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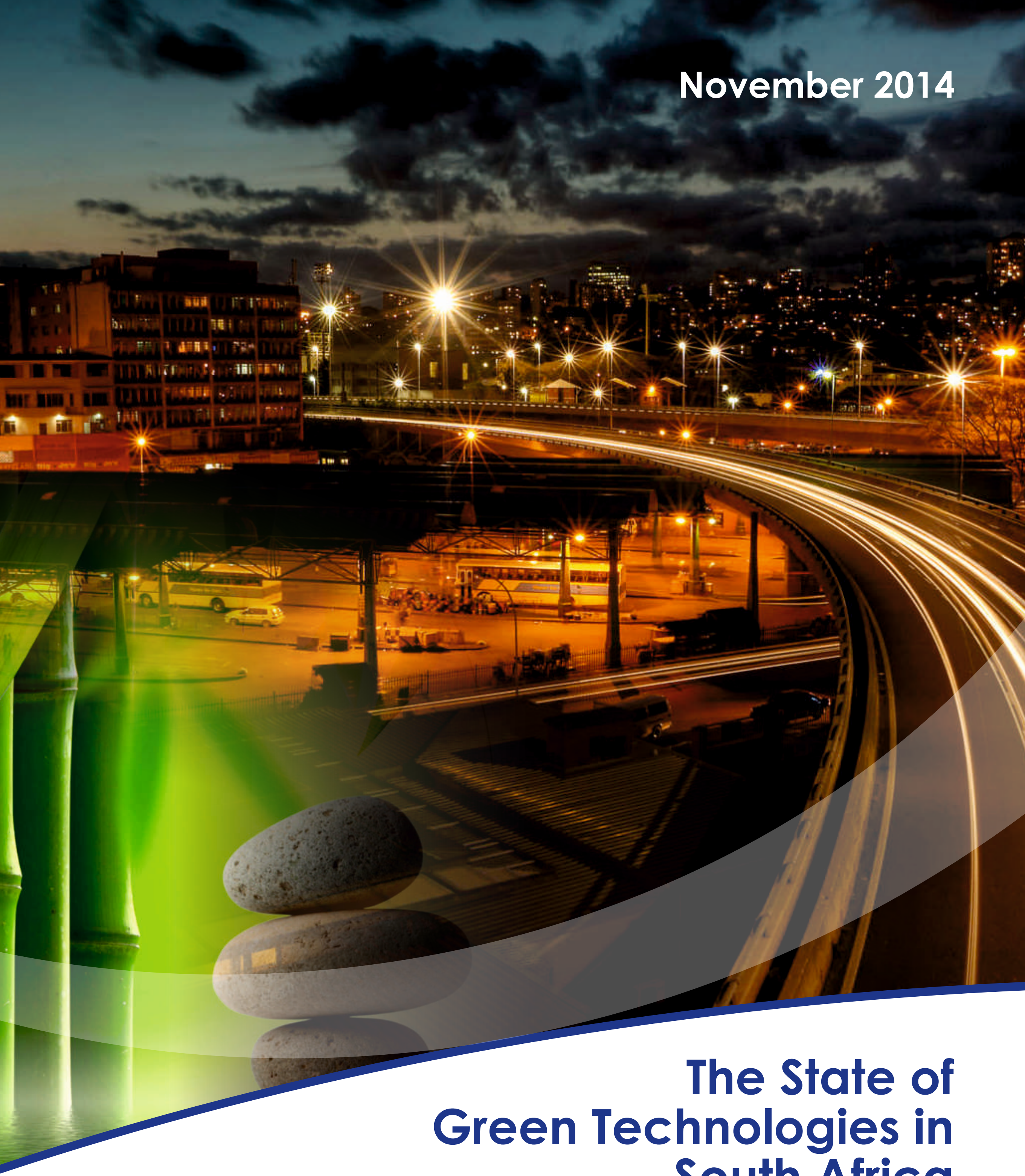

The State of Green Technologies in South Africa

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& technology
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REPUBLIC OF SOUTH AFRICA

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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science and scholarship for the benefit of society, with a mandate encompassing all scholarly disciplines that use an open-minded and evidence-based approach to build knowledge. ASSAf thus adopted in its name the term 'science' in the singular as reflecting a common way of enquiring rather than an aggregation of different disciplines. Its Members are elected on the basis of a combination of two principal criteria, academic excellence and significant contributions to society.

The Parliament of South Africa passed the Academy of Science of South Africa Act (*Act 67 of 2001*), which came into force on 15 May 2002. This made ASSAf the only academy of science in South Africa offcially recognised by government and representing the country in the international community of science academies and elsewhere.

THE STATE OF

GREEN TECHNOLOGIES IN SOUTH AFRICA

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LIST OF ACRONYMS

AMD	Acid mine drainage
ARC	Agricultural Research Council
ASSAf	Academy of Science of South Africa
BAU	Business as usual
BMU	Ministry of the Federal Republic of Germany (German: *Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit)*
BMW	*Bayerische Motoren Werke*
BP	British Petroleum
BRICS	Brazil, Russia, India, China, South Africa
CAIA	Chemical and Allied Industries' Association
CC	Carbon capture
CCS	Carbon capture and storage
CDM	Clean development mechanism
CDP	Carbon disclosure project
CEO	Chief executive officer
CIC	Climate Innovation Centre
COP	Conference of the Parties
CPV	Concentrator photovoltaic
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated solar power
DAFF	Department of Agriculture, Forestry and Fisheries
DBSA	Development Bank of Southern Africa
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DoE	Department of Energy
DST	Department of Science and Technology
the dti	Department of Trade and Industry
DWAF	Department of Water Affairs and Forestry
EDD	Economic Development Department
EE	Energy efficiency
EEDSM	Energy efficiency and demand-side management
EfW	Energy-from-waste
ETS	Emissions Trading Scheme
EU	European Union
FIT	Feed-in tariff
GDP	Gross domestic product
GE	Genetic engineering

GHG	Greenhouse gas
GMO	Genetically modified organism
IBT	Innovative building technology
ICSU	International Council for Science
ICT	Information and communications technology
IDC	Industrial Development Corporation
IDM	Integrated Demand Management
IEA	International Energy Agency
IGCC	Integrated gasification combined cycle
IPAP	Industrial Policy Action Plan
IPCC	Intergovernmental Panel on Climate Change
IPM	Integrated pest management
IPP	Independent power producer
IPR	Intellectual property rights
IRP	Integrated Resource Plan
ISMO	Independent System and Market Operator
IWA	International Water Association
M&E	Monitoring and evaluation
MFMA	Municipal Finance Management Act
MTSF	The Medium-term Strategic Framework
NBI	National Business Initiative
NCCRP	National Climate Change Response Policy
NDP	National Development Plan
NEES	National Energy Efficiency Strategy
NEDLAC	National Economic Development and Labour Council
NEM:WA	National Environmental Management: Waste Act
NEPAD	New Partnership for Africa's Development
NERSA	National Energy Regulator of South Africa
NFSD	National Framework for Sustainable Development
NGP	New Growth Path
NPC	National Planning Commission
NRCS	National Regulator for Compulsory Specification
NRF	National Research Foundation
NSDS	National Skills Development Strategy
NSI	National System of Innovation
NSSD	National Strategy for Sustainable Development
NWA	National Water Act
NWRS	National Water Resource Strategy
OECD	Organisation for Economic Co-operation and Development
PCGG	Presidential Commission on Green Growth
PC&Is	Principles, Criteria & Indicators
PCT	Patent Co-operation Treaty
PESTLE	Political, economic, sociological, technological, legal & environmental
PGMs	Platinum group metals
PPA	Power purchase agreement
PV	Photovoltaic

R&D	Research and development
RD&D	Research, development and demonstration
REBID	Renewable energy bids
REE	Rare earth element
REFIT	Renewable Energy Feed-in Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RSA	Republic of South Africa
RWH	Rainwater harvesting
SABS	South African Bureau of Standards
SADC	Southern African Development Community
SANEDI	South African National Energy Development Institute
SARi	South African Renewable Initiative
SBU	Strategic business unit
SFM	Sustainable forest management
SMEs	Small and medium enterprises
SOAAN	Sustainable Organic Agriculture Action Network
SPII	Support Programme for Industrial Innovation
SWH	Solar water heating
TAM	Technology Acceptance Model
TIPP	The Innovation Policy Platform
TMS	Target Management System
TRL	Technology readiness level
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
UNFCCC	United Nations Framework Convention on Climate Change
UNGC	United Nations Global Compact
UNICEF	United Nations Children's Fund
USA	United States of America
UTAUT	Unified Theory of Acceptance and Use of Technology
WHO	World Health Organisation
WIPO	World Intellectual Property Organisation
WRC	Water Research Commission
WWF	World Wildlife Fund

PREFIXES, UNITS AND GASES

Gases (units of measurement)		
Prefix	**Symbol**	**Power**
Kilo	K	10^3
Mega	M	10^6
Giga	G	10^9
Tera	T	10^{12}

Units of measurements	
Unit	**Definition**
h	hour
t	ton
W	Watt

Gases	
Unit	
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
NOx	Nitrogen oxides
SOx	Sulphur oxides

Currency	
Unit	
R	Rand
$	United States Dollar
€	Euro
DM	Deutschmark (West Germany: 1948 –1990)
KRW	South Korea won

FOREWORD

The Academy of Science of South Africa (ASSAf) is mandated to provide evidence-based science advice to government on matters of critical national importance. Transitioning to a green economy is one of the key imperatives of government, as highlighted in the National Development Plan (NDP). The implementation of green technologies is an integral part of the green economy, making this study on the State of Green Technologies in South Africa both timely and important.

The study has followed the traditional Academy consensus study methodology, in which a panel of experts, guided by the panel chair, undertakes the study. The advantage of this multi-perspective approach based on volunteerism is that it is free of partisan interest. As a result, the findings and recommendations are the best considered outcomes in the circumstances.

This report marks the ninth consensus study report that ASSAf has produced. It provides valuable information about policies that support the implementation of green technologies; valuable learning points from other countries; the state of green technologies in South Africa across a wide range of sectors; the drivers of and barriers to the implementation of green technologies; and finally, a set of recommendations that should be useful to policymakers charged with increasing the implementation and uptake of green technologies in South Africa. While the report was commissioned by the Department of Science and Technology, it will be useful to many other government departments, as well as be of value to the private sector.

The members of the study panel and the authors of the report, as well as the staff of the Academy, are acknowledged for the valuable work that they have done and for the care and attention with which they carried out their task.

Professor Daya Reddy
President: Academy of Science of South Africa

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This study was a collaborative effort involving many dedicated people. I want to thank the following people and organisations for ensuring the success of the study:

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Prof Eugene Cloete
Chair of the Panel

EXECUTIVE SUMMARY

One of the key drivers for an increasing focus on green technologies is climate change, although other concerns, such as the global energy and financial crises, resource depletion and environmental degradation have strengthened interest in green technologies. Further, it is recognised that there can be no transition to a green economy without green technologies and technological innovation.

The overall aim of this study is to document green technologies currently being utilised in South Africa, to identify gaps and opportunities for the utilisation of these technologies and to make recommendations to promote the growth of green technologies. The key questions are as follows:

- What are the green technologies currently available and in use in South Africa and how does South Africa compare globally in terms of the uptake of green technologies?
- What are the political, economic, sociological, technological, legal & environmental (PESTLE) factors that influence and impact on the implementation of green technologies in the South African context?
- In which sectors/areas are there gaps in the availability and/or implementation of technologies and potential for future growth?
- How best can new technologies be identified for transfer to South Africa and how should this be done to ensure that skills transfer is included?
- Are there opportunities for new innovative green technologies that can be implemented sustainably?
- Is there a set of indicators that can be used to measure successful implementation of green technologies?
- What is needed to promote and increase the use and development of local green technologies in South Africa?
- What recommendations are there for policies that would assist in promoting efficient and sustainable green technologies in South Africa?

A broad definition of green technologies is favoured, with the term embracing products, services and procedures that are used in green production and consumption processes. Green technologies have as their goals, *inter alia*, to minimise damage to the environment, conserve the use of energy and natural resources and, in the South African context where green technologies form an integral part of the green economy, an additional socio-economic goal that addresses job creation is considered vital.

The approach adopted in this study to assess the state of green technologies in South Africa is an Academy consensus study methodology, in which a panel of experts appointed by the ASSAf Council undertakes the task. The panel received evidence from a variety of sources and organisations and also commissioned research.

A public workshop entitled Green Technologies: Drivers, Barriers and Gatekeepers was also used as a forum to gather information. The panel compiled the report and through consensus agreed on the findings and recommendations. The report is peer reviewed and then considered by the ASSAf Council, which approves the report for publication and dissemination.

There are many factors that influence the deployment of green technologies in a country. These may include, *inter alia,* cost, geographic availability, technological readiness, job creation potential, availability of skills and government policy.

Chapter 2 addresses the critical question of how a country should prioritise green technologies, outlining various approaches. The greenhouse gas (GHG) inventory points to the energy sector as the prime contributor to GHG emissions, making this sector a key sector for interventions. A Technology Needs Assessment survey undertaken for the Department of Science and technology (DST) prioritises solar power and waste management under mitigation responses and the provision of water supply and sanitation under the adaptation responses. The McKinsey cost curve approach, which takes into account cost and potential to reduce GHGs, concludes that energy efficiency, the introduction of renewable energy, carbon capture and storage (CCS) and biofuels, offer the greatest opportunities. Technology readiness adds a further dimension and shows that of the renewable energy technologies, such as wind and solar, wind is more mature, with a technology readiness level (TRL) of 9. Solar thermal has a TRL of 6 – 8 and solar PV is some way behind with a value of 3 – 4. First generation biofuels also have a TRL of 9, with second generation biofuels scoring 5. Based on job creation potential, the natural resource management sector emerges as the most favourable, followed by energy generation, although it is cautioned against using employment potential as a single criterion as there are broader environmental, particularly climate change, benefits to be gained from activities in the other sectors. A further consideration is the number of manufacturing jobs created, with natural resource management creating none and energy generation the most at approximately 23 000.

Chapter 3 of the report focuses on the national policy context in South Africa. The growth and dissemination of green technologies is strengthened by a favourable policy environment. Policies can provide justification for the introduction of green technologies (e.g. climate change policies aimed at mitigating GHGs); promote innovation; provide incentives; alleviate barriers to implementation of green technologies; and through investment in research, foster an environment conducive to innovation and human capital development. Policies also help to guide the nature of and pace at which investment in green technologies occurs.

South Africa is regarded as having a favourable policy environment when it comes to green technologies. A chronological account of relevant national policies is given, with the point of departure being the broad, overarching National Framework on Sustainable Development. There are a large number of overarching and sector-based policies that refer either directly or indirectly to green technologies. It was also noted that while favourable policies are a necessary driver for success in green technology development and implementation, they are not a sufficient condition. Green technology programmes require a balanced mix of technical, financial and legal professional service providers, innovative funding and interdepartmental leadership, and project championship to be successful.

The need for this balance is very relevant for the South African situation, where there tends to be an over-emphasis on creating a favourable policy environment, with some neglect of other important factors.

Chapter 4 provides an international context for the analysis of the current status of, and future priorities for, green technologies in South Africa. It starts by summarising global trends in green technologies in the energy, water, sanitation and waste sectors. The chapter draws on some of the available indicators of green innovation and its impacts and then sets out some considerations for countries that are seeking to learn lessons from international experience. This focuses on technology and industry-focused 'catching up' strategies that have been pursued by some developing countries, and the role of technological capabilities and policy frameworks in these strategies.

Case studies of two countries that have had particularly strong 'green growth' strategies, *viz*. Germany and South Korea, are presented. Whilst the energy sector has been central to green growth strategies in both countries, there are some differences in the way green technologies are conceptualised. The differences are particularly apparent in the field of nuclear power. In South Korea,the development and deployment of nuclear power is part of the national green growth agenda and is prioritised in the country's R&D strategy. On the other hand, in Germany, the planned nuclear phase-out combined with challenging national emissions reduction targets have shifted the focus to renewable energy.

Despite these differences, a common feature between the two countries is that green growth is seen as a way to develop their economy and enable a transition to a new economic model. In addition to supporting green technology diffusion in their domestic markets, a focus on exports and achieving world leader status is considered key to long-term economic growth.

The framework used in this report to assess the state of green technologies is sector-based.

Chapter 5 provides an overview of the state of green technologies in energy, water, waste and sanitation in South Africa, as well as green technologies in sectors such as industry, mining, agriculture, information and communication technology (ICT), health, transport and buildings.

There is a strong emphasis on green technologies in the energy sector, as transformation in this sector is central to decoupling economic growth from negative ecological impacts and excessive resource use and shifting to a low-carbon growth path. In sectors other than energy, there has been limited progress in implementing green technologies, with the general conclusion that South Africa's record in terms of the uptake of green technologies is below average. This is borne out by global ranking data. According to the CleanTech Group and WWF Global Cleantech Innovation Index 2012, South Africa is ranked 28 out of 38 countries and is below the ranking of other BRICS (Brazil, Russia, India, China and South Africa) countries (e.g. Brazil (25th), India (12th) and China (13th)). South Africa has average scores for general innovation drivers, such as enabling institutions and infrastructures and commercialised cleantech innovation, but performs poorly on cleantech-specific innovation drivers and emerging cleantech innovation. The same report showed that while South Africa raised an average amount of green technology-related funds, the country has limited green technology friendly government policies (contrary to conclusions drawn in this study), and local investors.

South Africa also performed poorly in terms of venture capital investments in green technologies and the number of environmental patents attributable to South African institutions. South Africa is one of the most carbon-intensive economies globally, and national government has committed strongly to transitioning to a green economy and being a clean technology leader. However, like many developing countries, South Africa has been slow to develop and adopt green technologies despite much enabling legislation. The implicit assumption embedded in these policy documents is that the systems, such as financial, infrastructural, resources and skills, required to be a technology leader are in place and work efficiently in all respects, however, in many instances this is not the case.

Energy: Particular focus areas included energy efficient technologies, renewable energy technologies, as well as technologies aimed at reducing the environmental impacts of coal. South Africa has been slow to introduce renewable energy technologies, but the recent improved progress in this regard was noted. Given South Africa's high dependency on coal, clean coal technologies must continue to receive attention. Energy efficient technologies received relatively early attention and major investments have been made in both the public and private sectors.

The priority areas for South Africa from a renewable energy perspective, given the policy direction, are those of solar, wind and bioenergy resources. Hydropower potential is limited due to the small number of rivers suitable for generating hydroelectricity and current and projected water limitations in the country.

The country has amongst the best solar energy resources in the world – abundant sunshine, together with low precipitation and vast tracts of unused flat land. To date, very little has been exploited. Currently, concentrated solar power (CSP) is expensive compared with fossil fuel-based plants and will need a variety of incentives to make it cost-effective. However, South Africa could position itself as a leading global player in CSP in the future. To date, two large 100 MW CSP projects have been commissioned. Another opportunity is that the materials used to construct CSP plants are (mostly) readily available and many of the components can be manufactured locally. There is potential for South Africa to position itself In terms of technology development to support photovoltaic (PV) applications. The current roadmap highlights that South Africa should primarily consider crystalline silicon (wafer, cell), not only to create a knowledge base for growing the market in the country and elsewhere in Africa, but also to be able to compete in that market – in terms of establishing manufacturers across the PV value chain.

Wind farms offer the largest immediate potential for input into the national electricity grid, and for significantly alleviating South Africa's power supply shortage. The technology is mature, and is mainstreamed globally.

There is also considerable potential for biofuels, particularly when advanced second generation biofuel technologies come to fruition.

Water: Provision of potable water to all people in South Africa presents a challenge and there are millions of people without access to a potable water supply. This presents an opportunity for the development of innovative, low-cost green technologies aimed at potable water provision. Examples include solar water pasteurisation, ultraviolet disinfection and rainwater harvesting. Nanotechnology also has a role to play in improved water quality. South Africa also faces many water quality challenges linked to urban and industrial activities. These include the management of algal blooms on dams and acid mine drainage (AMD). Increasingly, green technologies are being used to solve these problems.

Waste: Green technologies within the waste space are technologies that will facilitate a move up the waste hierarchy from disposal through to recovery, recycling, reuse and waste prevention.

Sanitation: Green sanitation does not favour a particular technology, but embraces a philosophy of recycling resources. The question is whether urine and faeces can be made safe for crop production. The challenge therefore is to safely reticulate human-derived nutrients. In order to save energy, the case can be made for decentralised systems, incorporating cost-effective solutions and a holistic interdisciplinary approach.
This opens up a wide range of sanitation options.

Industrial sector: The implementation of green technologies in industries aims to minimise the use of hazardous materials and increases energy efficiency during a product's lifespan, as well as improve resource efficiency and water efficiency. Many opportunities exist for new technologies that could green the manufacturing process. Examples include the use of light-weight materials, methods of marking products so that a product's life cycle can be traced and digital or additive manufacturing.

Mining sector: This sector has a reputation as a major polluting sector, yet ironically, it is the key to the introduction of green technologies in many other sectors. The mining sector is the source of raw materials used, for example, in hybrid cars, modern wind turbines, energy efficient lights and motor vehicle catalytic converters. The negative impacts will need to be managed and balanced against the benefits that the mining sector offers to the broader economy and at the same time highlight the importance of sound environmental management within the mining sector itself and the value of green mining.

Agricultural sector: This sector was one of the first to apply green technologies through recycling of waste for use as fertiliser (composting, manure application) and sound conservation management. It is also responsible for many negative environmental impacts which present good opportunities for application of modern green technologies to improve production efficiency and reduce the negative environmental impacts. Green technologies considered include conservation agriculture, biogas production, precision agriculture, biotechnology, integrated pest management and organic farming.

ICT sector: This sector has the potential to play a fundamental role in enabling system-wide benefits, primarily through efficiency improvements that bring together various systems, software, data and infrastructure.

Health sector: Green technologies can be implemented across the sector aimed at implementing energy efficiency and clean energy generation; reducing water consumption; reducing the volume and toxicity of waste and ensuring safe disposal of waste; ensuring safe disposal of pharmaceuticals; following green building design principles and procuring food locally.

Transport sector: Transport is the third largest source of GHG emissions in South Africa. Since an effective transport system is a key driver of economic growth and social development, one of the strategic focus areas outlined in the National Development Plan is the prioritisation of transport solutions that are safe, affordable and effective. Development and uptake of green technologies in the transport sector are therefore an important strategy. Road transport accounts for 87% of transport emissions and presents as the sub-sector where the use of green technologies will have the greatest impact. There are many green technologies that have been implemented or are being investigated within the transport sector internationally, some of which are in use or under investigation in South Africa, while others have the potential to be acquired through technology transfer mechanisms. Examples include the use of green fuels, various green paving systems and green materials used in the manufacture of transport systems.

Building sector: The construction industry is also a significant consumer of resources, especially materials, energy and water. In South Africa, buildings account for 23% of electricity used, and a further 5% in the manufacturing of construction products. The construction industry has traditionally been a slow adopter of new technologies in general, mainly due to the perceived associated risks. The building sector, in particular, is reluctant to adopt new technologies due to potential buyer resistance. It was concluded that major reforms are necessary to respond to the various challenges facing the sector in terms of the implementation of green technologies.

There are many barriers that inhibit innovation and stand in the way of more effective implementation of green technologies in South Africa. Those highlighted in the report (**Chapter 6**) include: institutional challenges, pertaining to the lack of a coherent policy framework; government bureaucracy, referring to complex and lengthy government processes, and a lack of political will, that are delaying and even preventing green investment and the implementation of green projects; skills shortages; intellectual property rights (IPR) barriers; South Africa's poor track record in adopting foreign technologies; financial barriers, particularly funding during the 'valley of death' stage to ensure commercialisation and scale-up of technologies; and finally, a lack of market information and an understanding of how to address human behaviour.

Overcoming these barriers requires interventions that support green transition. Various categories of instruments that could assist in the development and implementation of green technologies were considered. These included: regulatory instruments, with South Africa having an abundance of relevant policies and an enabling policy environment; economic instruments, with South Africa having a range of financial instruments such as environmental taxes, incentives and subsidies to support the growth of green enterprises; research and education instruments, which were recognised as critical to successful implementation of green technologies but acknowledging that there is a skills development lag; cooperation instruments, such as voluntary agreements and interventions that support technology transfer, with the latter not having demonstrated great success to date in South Africa (e.g. clean development mechanism (CDM)) and the latter having had some measure of success; and finally, information instruments, aimed at plugging the information gaps and of which many recent successful examples were given.

Perspectives from the business sector are considered in **Chapter 7**. Like many emerging industries, increased uptake of green technologies requires support from both the private and the public sectors. Business is faced with the challenge of reducing pollution, waste and resource consumption to minimise environmental impacts, while at the same time, continuing to grow and increase profitability, and acting as a stimulus for innovation in the private sector. The focus of this chapter is on the key role for the business sector in South Africa in terms of green technology development and uptake, the challenges and opportunities around diffusion of green technologies and then finally, to explore opportunities for enhancing the role of business in green technology implementation. The various roles that the private sector plays in green technology innovation and deployment are summarised as developer/innovator; manufacturer; distributor/user; and partner/collaborator.

Chapter 8 addresses social and behavioural aspects of implementing green technologies. There are many factors that determine the success or failure of a specific technology, with the most common reason often being attributed (sometimes incorrectly) to cost. While cost is an important component, it is suggested here that the adoption and use of technology is less about cost and the technical qualities of the technology, and more about being socially bound; being determined by access to education and training, the perceived application within a society and by individual ability.

Adoption of green technologies is a process that takes place over a period of time, with significant interactions required between the adopter and the target technology. The logical starting point relates to two aspects of awareness: (1) awareness that a technology exists, and (2) awareness that the specific technology may have some positive impact on socio-economic or environmental upliftment for the individual or the individual's community. At this point it is vital that there is sufficient communication by government, consumer groups, and green technology innovation companies so that people are aware of the existence of the technology, as well as the potential benefits of that technology. It is important to consider communication networks other than traditional media such as the power of early adoption by significant people (e.g. celebrities, politicians, business leaders, etc.), user-friendly websites, education at schools, and online social networking. Next, one needs to pay close attention to the socio-economic environment in order to establish a social environment conducive to technological adoption. Technology adoption can only be considered if people actually have access to the target technology. Government can assist at this point by providing incentives such as subsidies, tax relief, and eco-labelling. Similarly, government can assist by instituting barriers to non-adoption such as taxes (e.g. carbon emissions tax for vehicles), government-regulated minimum costs, and raising disposal costs.

The development of an evaluation framework for measuring the implementation of green technologies is discussed in **Chapter 9**. The approach is based on the Principles, Criteria & Indicators (PC&Is) framework, from which a set of robust input and output indicators can be developed through a consultative process. Six principles, reflecting the broad goals of green technology implementation in the South African context were identified as: boosting economic growth; creating employment opportunities; facilitating the sustainable use of natural resources; reducing waste and pollution; reducing dependency on non-renewable resources; and addressing inequality and historical imbalances. In order to ensure that these goals are achieved, a set of criteria or management principles is identified. They are: increasing financial investment in research and development (R&D) to improve opportunities for the development and dissemination of green technologies; developing the necessary skills and capacity to foster innovation and provide the knowledge base and skills to facilitate uptake of green technologies; creating a business environment that is conducive to the uptake/diffusion of green technologies; ensuring that the development and deployment of green technologies contributes to ecological sustainability; ensuring that new green job opportunities are 'decent' and target previously disadvantaged and marginalised groups; and ensuring that green technologies are utilised to improve quality of life and basic service delivery. The development of a set of indicators is proposed as a follow-up consultative study.

Finally, in **Chapter 10**, the key findings are summarised and a consolidated set of nine recommendations aimed at promoting the implementation and development of green technologies in South Africa is provided. The recommendations are as follows:

1. **Policy Certainty and Policy Coherence**
   Ensure that policies play an enabling role by: setting clear targets and including mechanisms to assist in meeting those targets; instilling certainty in the market; and, ensuring that there is policy co-ordination between different government departments.

   Make provision for a regular review of the effectiveness of green technologies policies to allow for learning to be incorporated.

2. **Implementer and Developer Roles**
   Prioritise niche areas for local development of green technologies based on existing innovation capacity and encourage transfer of green technologies that have a good socio-technical fit with the local context. It makes sense to prioritise and maximise synergies with current industrial and other capabilities in South Africa but there is also a need to think about and develop capabilities in new niche areas.

3. **Creation of an 'Entrepreneurial State'**
   Government should consider itself as more than an enabler of green technologies but should actively shape the market through sound investments in R&D, education and training, and through the implementation of market incentives.

4. **Skills Transfer and Innovation Capacity**
   Government should focus on strengthening the National System of Innovation (NSI), ensuring interconnectedness between role players and skills development at tertiary level.

5. **Focus on the Market**
   Ensure that market demand is not neglected in favour of a focus on the supply-side of green technologies. There is a need for a targeted communication strategy to promote uptake of green technologies by the public and a need to plan for the export market, particularly within Africa.

6. **Alignment with South Africa's Development Needs**
   South Africa's development needs, particularly job creation, poverty alleviation and the need to overcome equity imbalances, should inform and direct, but not prescribe, green technology investment strategies.

7. **Development of Indicators**
   Initiate a follow-up study to identify a set of indicators for the monitoring and evaluation (M&E) framework for green technology uptake in South Africa.

8. Green Technology Hubs

Municipalities should consider the establishment of green technology hubs to foster the development of green technologies.

9. Systematic Evaluations of Failed or Discontinued Projects

There should be systematic reviews of projects, particularly failed or discontinued projects, so that learning can be enhanced.

Chapter 1

1 INTRODUCTION

1.1 Background to the Study

The Academy of Science of South Africa (ASSAf) was tasked by the Department of Science and Technology (DST) with conducting this study due to its unique position as a nationally recognised body which provides scientific and evidence-based advice to government on critical scientific issues. The Academy is also well placed to provide an assessment of the state of green technologies in South Africa and to provide recommendations to increase the development and use of green technologies. As the body that holds the Membership of the most prominent scientists in the country, the Academy is able to draw on the expertise of a large number of people who serve in a voluntary capacity to contribute towards the objectives of the study.

The study brief and specific objectives of this study are presented in Box 1.1.

Box 1.1: Study brief

The aim of this study is to document green technologies currently being utilised in South Africa, to identify gaps and opportunities for the utilisation of these technologies and to make recommendations to promote the growth of green technologies.

Key questions

- What are the green technologies currently available and in use in South Africa and how does South Africa compare globally in terms of the uptake of green technologies?
- What are the political, economic, sociological, technological, legal & environmental (PESTLE) factors that influence and impact on the implementation of green technologies in the South African context?
- In which sectors/areas are there gaps in the availability and/or implementation of technologies and potential for future growth?
- How best can new technologies be identified for transfer to South Africa and how should this be done to ensure that skills transfer is included?
- Are there opportunities for new innovative green technologies that can be implemented sustainably?
- Is there a set of indicators that can be used to measure successful implementation of green technologies?

- What is needed to promote and increase the use and development of local green technologies in South Africa?
- What recommendations are there for policies that would assist in promoting efficient and sustainable green technologies in South Africa?

1.2 Approach and Methodology

The study was approved by the ASSAf Council on 17 October 2012 and the eight-member panel chaired by Professor Eugene Cloete was appointed. The full membership of the panel is presented in Table 1.1 and membership biographies in Appendix 1.

Table 1.1: Composition of the study panel

Name	Affiliation
Prof Eugene Cloete	Stellenbosch University
Prof Chris Buckley	University of KwaZulu-Natal
Dr Linda Godfrey	Council for Scientific and Industrial Research
Prof Diane Hildebrandt	University of South Africa
Dr Makhapa Makhafola	Mintek
Prof Anastassios Pouris	University of Pretoria
Prof Emile van Zyl	Stellenbosch University
Prof Jim Watson	UK Energy Research Centre

The panel met five times. At the first meeting on 15 and16 January 2013, a presentation was made by Dr Henry Roman, Director: Environmental Services and Technologies of the DST to provide the background to the study, the expectations of DST and an overview of relevant policies. Subsequent meetings were held on 5 February 2013, 2 May 2013, 11 September 2013 and 14 February 2014. A workshop, focused on Green Technologies: Drivers, Barriers and Gatekeepers, was held on 10 September 2013.

The final draft report was submitted for peer review in May 2014. Following peer review by experts, listed in Appendix 2, the panel finalised the report and submitted it to the ASSAf Council for approval. The ASSAf Council approved its publication at a Council Executive meeting on 29 July 2014.

1.3 Global and National Context for Growth in Green Technologies

One of the key drivers for an increasing focus on green technologies is climate change. While it is acknowledged that this may be the dominant driver, other concerns related, for instance, to the global energy and financial crises, resource depletion and environmental degradation have strengthened the growth in green technologies. In searching for solutions to these crises and ways to carve a new development path, the notion of a green economy emerges as a means to ensure sustainable development. A critical aspect of the proposed new development path is the decoupling of economic growth from environmental degradation (UNEP, 2011).

Maintaining ecological integrity is crucial for economic growth and social well-being. There are two ways in which decoupling can be achieved: first, through resource decoupling (i.e. using fewer resources to achieve the same level of growth and well-being), and second, through impact decoupling (i.e. decoupling the use of resources from the impact on ecosystems). The growing need for this decoupling drives green technology innovation and diffusion. Implementing green technologies can assist by providing alternative sources of energy, by improving efficiency and productivity, and by reducing waste and pollution. In turn, these improvements have positive spin-offs for job creation and improved environmental quality of life.

In South Africa, government recognises the value of adopting a greener, more sustainable development path. Green technologies have the potential not only to stimulate economic growth, create new job opportunities, and mitigate ecological risks, but they can also be implemented to improve living conditions and speed up service delivery, thereby fulfilling national social justice commitments. To adopt this green development path successfully, various efforts have been made by the state to support the green economy, as will be seen in Chapter 3. Despite these efforts, however, there are still obstacles that prevent green technologies from realising their full potential. These will be unpacked in this report.

1.4 Green Economy and Green Technologies Relationship

The term green economy was coined in Blueprint for a Green Economy (Pearce *et al.*, 1989), but did not receive much attention until 2008, when in response to the global financial crisis and the threat of a possible global recession, the United Nations Environment Programme (UNEP) raised the idea of 'green stimulus packages' that could stimulate a 'green economy' (Atkisson, 2012). The concept gained traction in the lead up to the Rio+20 conference, forming one of the two themes addressed at the 2012 United Nations (UN) Conference on Sustainable Development or Rio+20 conference.

While there is no universally accepted definition of green economy, the UNEP has defined the green economy as "one that results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities. It is low carbon, resource efficient and socially inclusive" (UNEP, 2011). It is evident that the green economy is much more than a shift to green technologies. It is also about a social transformation that takes account of human well-being, addressing key aspects of job creation and poverty alleviation. It is an approach that considers not only ecological sustainability and the limitations of resources and the deteriorating natural environment but takes an integrated view of sustainability that includes the socio-economic drivers as well.

In this interpretation, green technologies are a necessary, but not sufficient, component of the green economy. This was captured in a statement prepared by Gisbert Glaser on behalf of the International Council for Science (ICSU) in the preparations for the Rio+20 meeting which reads "the green economy should emphasise environmentally sustainable economic progress to foster low-carbon, socially inclusive development and investment in green jobs, clean technologies and green sectors". He went on further to state that there can be no green economy without green technologies and technological innovation.

1.5 Definition of Green Technologies

Green technologies are characterised by innovation and comprise a set of products, services and systems that are continuously evolving. Growth in recent years has been driven by climate change and more general environmental challenges that are confronting the world.

Various definitions of 'green technology' exist. The simplest definition defines green technology as a technology that is environmentally friendly or environmentally sound. Terms such as 'environmental technology', 'clean technology', 'cleantech' or 'low-carbon technology' are sometimes used, although low-carbon technology can be considered as a sub-set of green technology. Other less commonly used terms include climate-smart and climate-friendly technology.

A broad definition of green technologies is generally favoured; hence the definition does not only include 'end-of-pipe' technologies that reduce pollution, but integrated technologies that prevent pollutants from being generated during production processes, as well as new materials and more efficient production processes (EC, 2002). Green technology also means more than individual technologies; the term embraces products, services and procedures that are used to green production and consumption processes (UNESCAP, 2012).

A useful definition is provided by the Malaysian Ministry of Energy, Green Technology and Water, which defines green technology as "the development and application of products, equipment and systems used to conserve the natural environment and resources, which minimises and reduces the negative impact of human activities[1]".

They further note that green technology includes products, equipment or systems that:

- minimise damage to the environment;
- have zero or low GHG emissions;
- are safe to use;
- promote a healthy and improved environment for all life;
- conserve the use of energy and natural resources;
- promote the use of renewable resources.

These criteria can be considered as goals of green technologies and are universally applicable. Within the South African context, where green technology forms an integral part of the green economy, an additional socio-economic goal that recognises the high unemployment rate in the country and strives to address job creation is considered vital. Over and above all these objectives, economic competitiveness will play a significant role in the implementation of green technologies.

(http://www.greentechmalaysia.my/index.php/green-technology/introduction.html)

1.6 Scope of Green Technologies

It is important to articulate our understanding of the scope of green technologies and to provide a coherent framework for assessing the state of green technologies. For example, green technologies can be categorised as follows (UNEP, 2003):

(1) Monitoring and assessment technologies which are used to measure the state or condition of the environment.

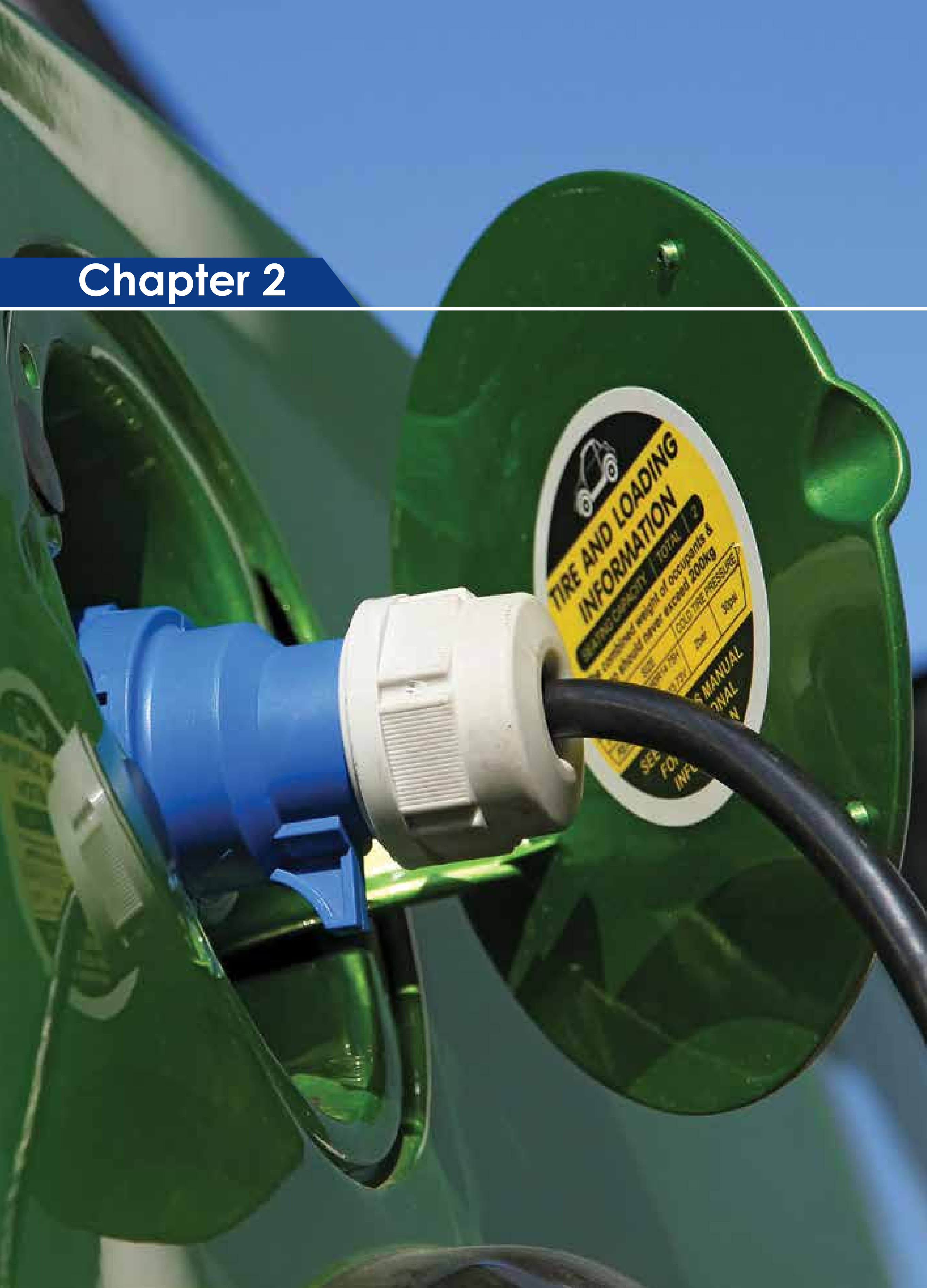
(2) Prevention technologies that minimise or prevent the production of substances that harm the environment. These may include product substitution, ways of altering human activities and the redesign of a production process.

(3) Control technologies which act on substances released into the environment, rendering them harmless at source.

(4) Remediation and restoration technologies which aim at improving the environment that has been damaged by human activities.

The framework used in this report to assess the state of green technologies is sector-based. First, green technologies in energy, water, sanitation and waste are presented. Then green technologies in each of the following sectors are considered: manufacturing, mining, agriculture, information and communications technology (ICT), health, transport and building. It is recognised that there will be some inevitable overlap with the earlier sections but it was deemed important to provide such a structured and comprehensive account. Duplication of content is avoided as far as possible.

Chapter 2



2 GREEN TECHNOLOGIES LANDSCAPE: NEEDS AND PRIORITIES

2.1 Introduction

There are many factors that influence the deployment of green technologies in a country. These may include, *inter alia,* cost, geographic availability, technological readiness, job creation potential, availability of skills and government policy. Questions also arise as to how a country should prioritise green technologies.

This chapter addresses some of these prioritisation issues.

2.2 Greenhouse Gas Emissions

While it is recognised that the definition of green technologies used in this report goes far beyond pollution control technologies, a useful point of departure is the contribution of various sectors to GHG emissions in South Africa, as this illustrates where the greatest need for intervention lies. According to the most recently available national GHG inventory, which is based on 2000 data (DEAT, 2009), the percentage contribution to CO_2 emissions is: energy supply and consumption, 78.9%; industrial processes, 14.1%; agriculture, 4.9%; and waste, 2.1%.

This breakdown accords with global trends and perhaps explains the dominance of the energy sector when it comes to matters of the green economy and green technologies. Certainly, much of the sector-based policy focus in South Africa has been on energy (See Chapter 3). By introducing green technologies into the energy sector, one is likely to have the greatest impact on GHG emissions and reporting to the United Nations Framework Convention on Climate Change (UNFCCC).

2.3 South Africa's Technology Needs Assessment

A stakeholder-driven technology needs assessment was undertaken as part of South Africa's commitment to the UNFCCC (DST, 2007a). It expressed South Africa's priorities in terms of green technologies and identified barriers to technology transfer and measures to overcome them. Its purpose was to guide investments from developed country partners, in particular, and to increase opportunities for commercialisation and/or diffusion of green technologies.

Taking into consideration only those technologies that had not yet reached full commercialisation and where technology transfer was required, technologies were ranked by experts (DST, 2007a). The method of ranking involved the definition of four broad criteria: relevance to climate change; alignment with national goals; market potential; and skills and capacity building. Within each criterion a number of measures were identified and weighted on a scale of 1 (low importance) to 3 (critical importance). For every measure, technologies under consideration were then assigned a value of 1 (low importance) to 3 (critical importance) and the total calculated. The total was then weighted relative to the value ranking of the defined measures to produce a percentage indicating the relative importance of the technology according to the defined measures. The results are summarised in Table 2.1.

Table 2.1: Key sectors and associated prioritised technologies (after DST, 2007a)

Response	Sector	Sub-sector	Measures/Technology Options	Total Score (%)
Mitigation	Energy	Electrical Energy Generation	Solar power	85.6
			Clean coal technologies	75
			Wind power	75
		Industry/Mining	Boiler improvement	78.8
		Waste Management	Promote source reduction, recycle and reuse	84.8
	Agriculture, Land Use and Forestry		Conservation agriculture	83.3
			Control of biomass burning in wildfires (including forests)	81.8
	Transport		Improvement of urban mass transport systems	81.8
			Fuel-efficiency improvements	81.1
Adaptation	Human Health		Provision of water supply and sanitation	90.4
			Control of the spread of vector-borne disease	87.1
	Agriculture, Land Use and Forestry		New crop species and cultivars	88.6
			Information technology	87.1
			Macro-economic diversification and livelihood diversification in rural areas	82.6
			Pest management	80.3
			Vulnerability research	80.1
	Water Resources		Technologies that promote water efficiency	81.8
	Built Environment and Infrastructure		Climate-sensitive building design	81.1

2.4 McKinsey Cost Curve to Prioritising Green Technologies

Faced with many possible green technologies in various stages of development and spread across sectors such as energy, water and waste, a useful starting point is the cost curve approach introduced by McKinsey & Co., which was refined and presented in their study, Pathways to a Low-carbon Economy (McKinsey & Co., 2010). More than 200 opportunities were compared across ten sectors and 21 geographical regions. While cost is not the only consideration, a global picture comparing green technologies in terms of their costs in reducing GHG emissions, offers a baseline of potential opportunities against which priorities that match national development needs can take place.

Figure 2.1 shows the emission reductions that are possible with technologies available today or with a high degree of certainty by 2030. The width of each bar is proportional to the potential of that opportunity to reduce GHGs and the height is proportional to cost, with the lowest cost abatement opportunities on the left-hand side and the highest on the right-hand side.

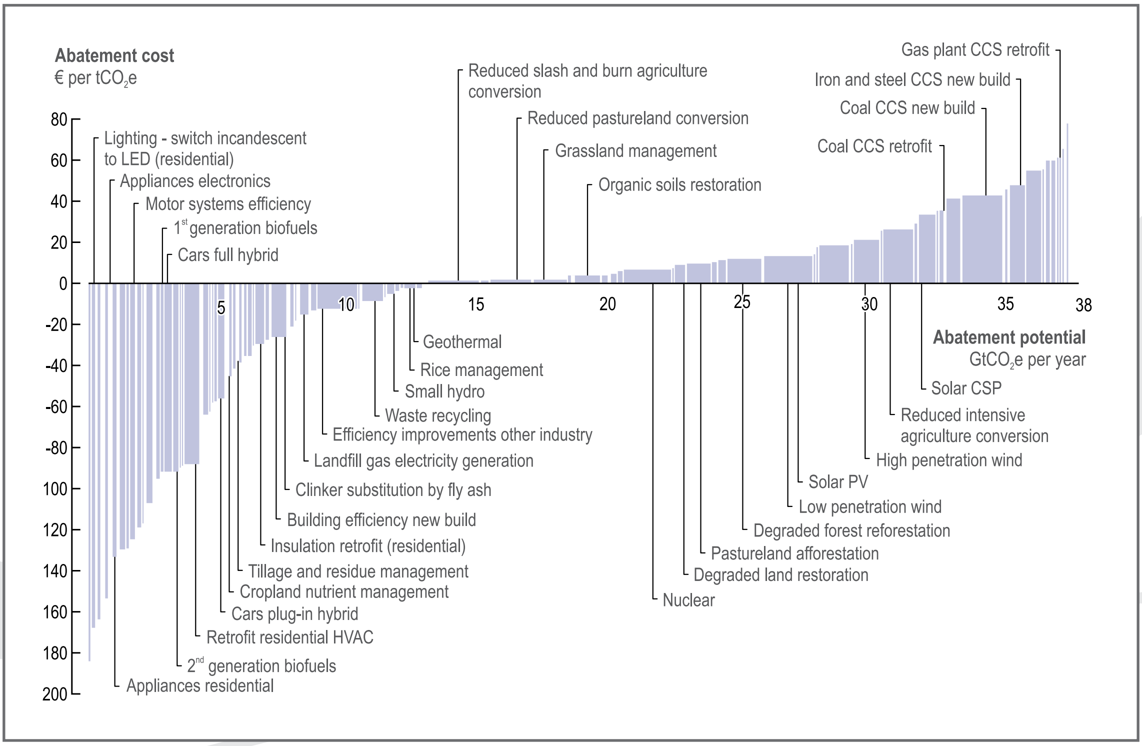


Figure 2.1: Global GHG abatement cost curve beyond business as usual – 2030

Note: The curve presents an estimate of the maximum potential of all technical GHG abatement measures below €80 per tCO_2e if each lever was pursued aggressively. It is not a forecast of what role different abatement measures and technologies will play.

Abatement opportunities lie in four categories:

(1) Energy efficiency – improving energy efficiency in vehicles, buildings, industrial equipment, etc.
(2) Low-carbon energy – shifting to renewable energy resources, equipping conventional power plants with carbon capture and storage (CCS), and replacing conventional transport fuels with biofuels.
(3) Terrestrial carbon (forestry and agriculture) – involves putting an end to tropical deforestation, reforesting marginal lands and sequestering more carbon in soils through changing agricultural practices.
(4) Behaviour change – there are many opportunities, such as shifting from road to rail transport, but it is recognised that behavioural changes are difficult to implement.

The first three categories are captured on the global GHG abatement cost curve (McKinsey & Co., 2010).

The analysis above is for the globe as a whole. Studies for individual countries have also been undertaken, with that for China (McKinsey & Co., 2009) being perhaps most relevant for South Africa. In terms of GHG abatement, the following priorities for China were identified:
(1) Replacement of coal with clean energy sources.
(2) Comprehensively adopting green cars.
(3) Improving waste management in high emission industries.
(4) Designing energy efficient buildings.
(5) Restoring China's carbon sink (forestry and agriculture).
(6) Rethinking urban design and adjusting consumer behaviour.

2.5 Technology Readiness Level

Technology readiness level (TRL) is a useful measure to assess the maturity of a technology and can guide decision-making (Table 2.2). Nine levels are defined, commencing with the lowest level (TRL 1), where the transition from scientific research is just beginning, to the highest level (TRL 9), where the technology has been thoroughly tested and has been successful in the operational environment.

Table 2.2: Definition of technology readiness levels (adapted after CAETS, 2013)

TRL 1:	**Basic principles observed and reported:** Lowest level of technology readiness. Scientific research begins to be translated into applied research and development.
TRL 2:	**Technology concept and/or application formulated:** Applied research. Theory and scientific principles are focused on specific application areas to define concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions.
TRL 3:	**Analytical and experimental critical function and/or proof-of-concept:** Proof-of-concept validation. Active R&D is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.
TRL 4:	**Component/subsystem validation in laboratory equipment:** Standalone prototyping implementation and testing. Experiments with full-scale problems or data sets. Basic technological components are integrated to establish that they will work together.
TRL 5:	**System/subsystem/component validation in relevant environment:** Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements.
TRL 6:	**System/subsystem model or prototyping demonstration in a relevant end-to-end environment (ground or space):** Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
TRL 7:	**System prototyping demonstration in an operational environment (ground or space):** System prototyping demonstration in operational environment. System is at or near scale of the operational system, with most functions available for demonstration and testing.
TRL 8:	**Actual system completed and 'mission qualified' through test and demonstration in an operational environment (ground or space):** End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and validation completed.
TRL 9:	**Actual system 'mission proven' through successful mission operations (ground or space):** Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

Based on these principles, various green technologies in the energy sector were assessed from a global perspective in terms of their ability to lower the carbon footprint and their TRL. The most promising initiative that would accelerate deployment was identified, as well as the technical and financial risks that act as barriers (Table 2.3) (CAETS, 2013).

Table 2.3: Technology ranking for green technologies in the energy sector (CAETS, 2013)

Technology	Ability to Lower Carbon Footprint*	Technology Readiness Level	Timescale for Wide Deployment (Years)	Most Promising Initiative for Accelerating Deployment
Hydro	1	9	Now	Design standardisation
Solar Thermal	1-2	6-8	10+	Efficient thermal energy storage
Advanced Solar Photovoltaic	2-3	3-4	15+	
Photo(Electro) Chemical	2-3	1-3	10-15	
Geothermal	1	4-5	15+	Hot dry rock demonstration plants of > 50MW
Wave Energy	1	4	15	High efficiency devices
Tidal Current	1	5	15	High efficiency devices
Tidal Barrage	1	9	5	High efficiency devices
Wind	1	9	Onshore – now Offshore – 5 – 10	Feed-in tariffs and commitments to technology deployment
Biomass	1	1st generation – 9 2nd generation – 5	1st generation – now 2nd generation – 5 – 8	Feed-in tariffs and commitments to technology deployment
Natural Gas	3	9	Immediate	Natural gas from unconventional geological formations Fuel cells
Coal (Including Integrated Gasification Combined Cycle (IGCC) and Carbon Capture(CC))	1-2	7	IGCC – 10 IGCC with CC – 20 Ultrasupercritical pulverised coal-fired (USCPC) with CC – 20	Carbon market and carbon emission constraints
Carbon Sequestration	1	6	10+	Carbon market and carbon emission constraints
Nuclear Energy	1	9	Generation II/III – now Generation IV – 15 – 25 Fusion – 35 – 50	Higher efficiency and improved safety

**Ability to lower carbon footprint is defined in terms of life cycle reduction of CO_2 generation compared to standard coal-based generation, where 1=80 - 100% reduction; 2=60 - 79%; 3=40 - 59%; 4=20 - 39%; and 5=0 - 19%.*

2.6 Job Creation Potential

Job creation is a top priority of government and features prominently in the NDP, which is described in Chapter 3. Targeting sectors that have the greatest job creation potential aligns well with government imperatives and is a means to prioritise investment and provide policy focus.

A landmark report on green jobs in South Africa (Maia *et al*., 2011) has estimated the direct employment opportunities (excluding multiplier effects) in various sub-sectors as a result of greening the economy. Table 2.4 summarises their findings and demonstrates that jobs associated with natural resource management are expected to be greatest over the short, medium and long-term time frames, increasing from around 43 000 direct jobs in the short term to over 230 000 direct jobs in the long term. Such jobs would include activities relating to biodiversity conservation, ecosystem restoration and soil and land management. The energy generation sector is expected to show considerable growth in employment opportunities, increasing from 13 500 direct jobs in the short term to 130 000 direct jobs in the long term. Energy and resource efficiency activities are expected to increase from 31 500 to 68 000 direct jobs from the short to long term. The category of emissions and pollution mitigation, rises from 8 400 to 32 000 new direct jobs over the same time frame.

Table 2.4: Direct green job creation potential in the long term (25 years) in various categories (after Maia et al., 2011)

Broad Green Economy Category		Segment	Technology/Product	Total Net Direct Employ-ment Potential	Net Direct Manu-facturing Employ-ment Potential
Energy Generation	**Renew-able (Non-fuel) Electric-ity**	Wind Power		2 105	5 156
		Solar Power	Concentrated solar power	3 014	608
			Photovoltaic power	13 541	8 463
		Marine Power		197	0
		Hydro Power	Large hydropower	272	111
			Micro/small hydropower	100	0
	Fuel-based Renew-able Energy	Waste-to-energy	Landfills	1 178	180
			Biomass combustion	37 270	154
			Anaerobic digestion	1 429	591
			Pyrolosis/gasification	4 348	2 663
			Co-generation	10 789	1 050
	Liquid Fuel	Biofuel	Bio-ethanol Bio-diesel	52 729	6 641
Energy Generation Sub-total				**130 023**	**22 566**
Energy and Resource Efficiency	Green Buildings		Insulation, lighting, windows	7 340	838
			Solar water heaters	17 621	1 225
			Rainwater harvesting	1 275	181
	Transportation		Bus rapid transport	41 641	350
	Industrial		Energy efficient motors	-566	4
			Mechanical insulation	666	89
Energy And Resource Efficiency Sub-total				**67 977**	**2 686**

Broad Green Economy Category	Segment	Technology/Product	Total Net Direct Employ-ment Potential	Net Direct Manu-facturing Employ-ment Potential
Emissions and Pollution Mitigation	Pollution Control	Air pollution control	900	166
		Electric vehicles	11 428	10 642
		Clean stoves	2 783	973
		Acid mine water treatment	361	0
		Carbon capture and storage	251	0
		Recycling	15 918	9 016
Emissions and Pollution Mitigation Sub-total			**31 641**	**20 797**
Natural Resource Management	Biodiversity conservation and ecosystem restoration		121 553	0
	Soil and land management		111 373	0
Natural Resource Management Sub-total			**232 926**	**0**
TOTAL			**462 567**	**46 049**

2.7 Concluding Remarks

The analysis presented in this chapter incorporates various perspectives, all aimed at trying to prioritise green technologies, either by sector or by type.

The GHG inventory points to the energy sector as the prime contributor to GHG emissions, making this sector a key sector for interventions.

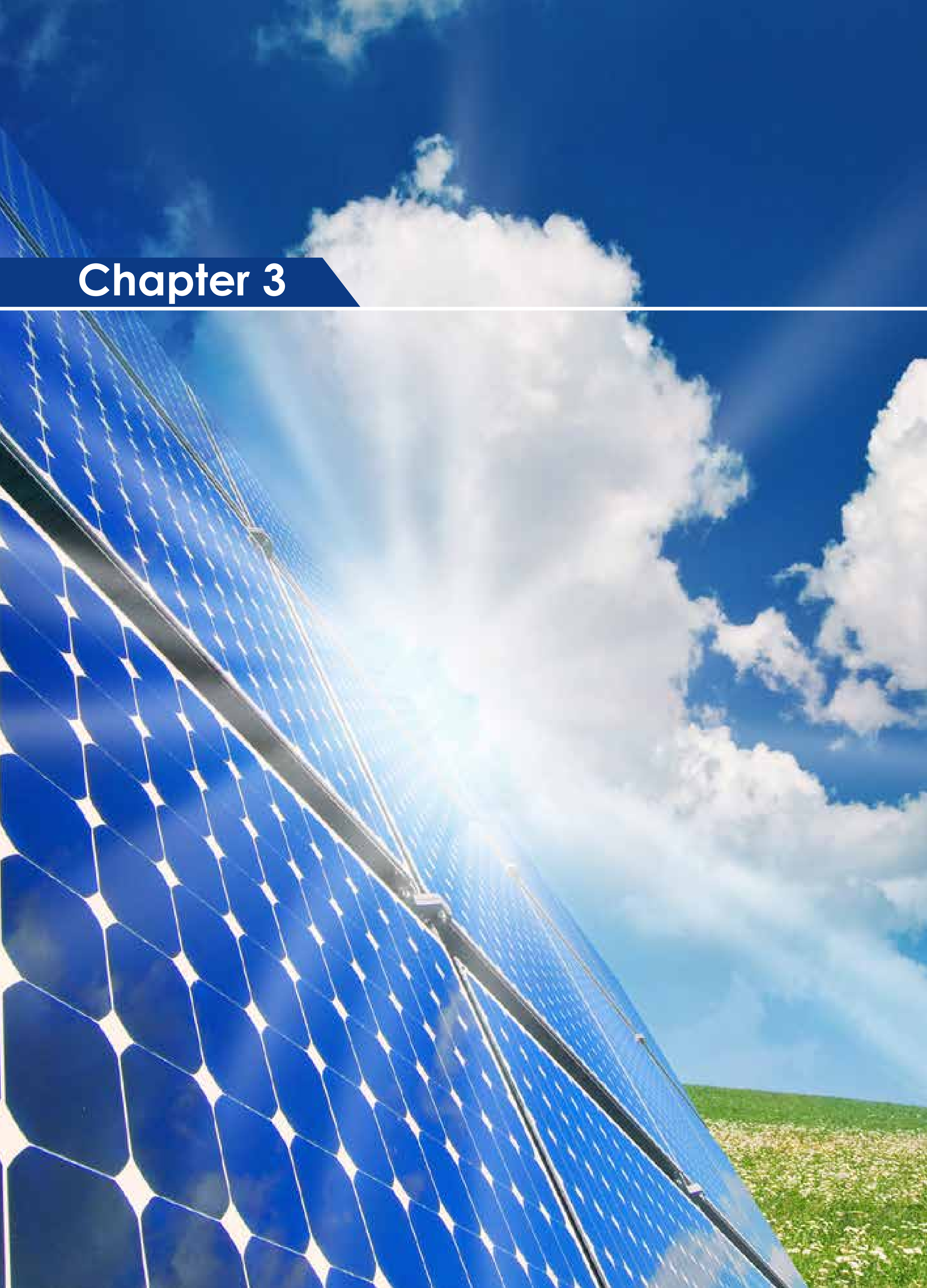
The Technology Needs Assessment survey (DST, 2007a) prioritises solar power and waste management under mitigation responses and the provision of water supply and sanitation under the adaptation responses.

The McKinsey cost curve approach takes into account cost and potential to reduce GHGs and concludes that energy efficiency, the introduction of renewable energy, CCS and biofuels, offer the greatest opportunities.

Technology readiness adds a new dimension and shows that of the renewable energy technologies, such as wind and solar, wind is more mature with a TRL of 9. Solar thermal has a TRL of 6 – 8 and solar PV is some way behind with a value of 3 – 4. First generation biofuels also have a TRL of 9, with second generation biofuels scoring 5.

Based on job creation potential, the natural resource management sector emerges as the most favourable, followed by energy generation, although it is cautioned against using employment potential as a single criterion as there are broader environmental, particularly climate change, benefits to be gained from activities in the other sectors. A further consideration is the number of manufacturing jobs created, with natural resource management creating none and energy generation the most at approximately 23 000. The analysis presented here has also not taken into account the skills level of the jobs created.

Chapter 3



3 NATIONAL LEGAL AND POLICY CONTEXT IN SOUTH AFRICA

3.1 Introduction

The growth and dissemination of green technologies are strengthened by a favourable policy environment. Policies can provide justification for the introduction of green technologies (e.g. climate change policies aimed at mitigating GHG emissions); promote innovation; provide incentives; alleviate barriers to implementation of green technologies; and through investment in research, foster an environment conducive to innovation and human capital development. Policies also help to guide the nature of and pace at which investment in green technologies occurs.

South Africa can generally be regarded as having a favourable policy environment when it comes to green technologies. Certainly, there is not a deficiency of pertinent overarching national policies, many of which are highlighted in this chapter. A chronological account of relevant national policies is given, with the point of departure being the broad, overarching National Framework on Sustainable Development (NFSD).

Compliance with international agreements is also important. South Africa is a signatory to the Kyoto Protocol, which provides the context for South Africa's commitment to reduce its GHG emissions and thereby drives the introduction of green technologies. This point is elaborated upon when discussing South Africa's climate change response. It is also true that growth and dissemination of green technologies can be driven by policies at the local level, but only a passing reference to relevant policies in some of the major metropolitan areas in South Africa is made later in this report.

While favourable policies are a necessary driver for success in green technology development and implementation, they are not a sufficient condition. It is important to note that green technology programmes require a balanced mix of technical, financial and legal professional service providers, innovative funding and inter-departmental leadership, and project championship to be successful.

3.2 Overview of National Policies driving Implementation of Green Technologies

3.2.1 The National Framework for Sustainable Development and the National Strategy for Sustainable Development

The NFSD, promulgated in 2008 (DEAT, 2008), established a broad framework that is intended to guide South Africa's development along a sustainable path. It set out the vision for sustainable development and identified five strategic priority areas or pathways that would guide subsequent implementation plans. Although broad, the NFSD provides an enabling policy for investment in green technologies.

Following on from the NFSD, a more binding strategy and action plan known as the National Strategy for Sustainable Development and Action Plan or NSSD 1 (2011 – 2014) was approved by Cabinet in 2011 (DEAT, 2011a). The original priority areas of the NFSD were slightly reformulated (Table 3.1); 113 interventions identified and 20 indicators established to monitor and evaluate progress. Lessons learned from NSSD 1 are expected to feed into NSSD 2 (2015 – 2020).

Table 3.1: Strategic priorities of the National Strategy for Sustainable Development Action Plan (DEAT, 2011a)

Priority Areas	NSSD 1
1	Enhancing systems for integrated planning and implementation
2	Sustaining our ecosystems and using natural resources efficiently
3	Towards a green economy
4	Building sustainable communities
5	Responding effectively to climate change

3.2.2 Medium-term Strategic Framework

The Medium-term Strategic Framework (MTSF) sets out the government priorities for the electoral mandate period, 2009 – 2014 (The Presidency, 2009). Although not mentioned as a specific priority area, growth in green technologies aligns well with the outcome to create decent employment through inclusive economic growth, the outcome stating that environmental assets and natural resources are valued, protected and continually enhanced, as well as the outcome that highlights the implementation of the NFSD. Various policy responses implemented in response to the MTSF have created an enabling environment for renewable energy and water management projects.

At the time of writing, the final version of the MTSF for the electoral period 2014 – 2019 was not available, but it is anticipated that it will address the same priorities as the NDP (See Section 3.2.7) and build towards the realisation of the 2030 vision.

3.2.3 Framework for South Africa's Response to the International Economic Crisis

This economic policy document (RSA, 2009a), the Framework for South Africa's Response to the International Economic Crisis, which was published in February 2009, was the first policy document to refer specifically to green jobs and has led to substantial green investment, particularly in renewable energy (Montmasson-Clair, 2012). It was produced as a result of collaborative efforts of government, business and labour and was facilitated by the National Economic Development and Labour Council (NEDLAC).

3.2.4 New Growth Path

The New Growth Path (NGP), launched in November 2010, aims to increase economic growth rates to between 6% – 7% per annum (Economic Development Department (EDD), 2010). The NGP follows on from the Reconstruction and Development Programme, the Growth Employment and Redistribution Programme and the Accelerated and Shared Growth Initiative of South Africa.

The cornerstone of the NGP is job creation, with a target of five million new jobs by 2020 and of these, 300 000 jobs in the green economy. Other priority areas are infrastructure development, agriculture, mining, manufacturing and tourism. The NGP aims to reduce the unemployment rate to 15% by 2020. It is envisaged that most of the projected new jobs will come from the private sector.

Although criticised for being an aspirational document that is lacking in operational details (Natrass, 2011), the NGP set the target for the number of jobs to be created in the green economy, a figure that is widely quoted.

3.2.5 Support Programme for Industrial Innovation

The Support Programme for Industrial Innovation (SPII) has essentially been operating since 1993, but has undergone various changes over time to improve its accessibility. It aims to support the development and commercialisation of new technologies in South African industry by providing financial assistance for innovative products and/or processes, particularly those at the 'proof of concept' stage. The programme is managed by the Industrial Development Corporation (IDC) on behalf of the Department of Trade and Industry (the dti).

At the end of the 2009/2010 financial year, there were concerns about discrepancies in the level of SPII's outstanding commitments. A moratorium was placed on new applications and a review undertaken. Dormant and inactive projects were cancelled and according to the 2012/2013 Annual Report (SPII, 2013), there has been a gradual improvement in the effectiveness and efficiency of the programme. Notwithstanding its administrative challenges and the need to address some under-performing schemes, it remains a key intervention. Its impact is monitored through indicators such as local and export sales, taxes paid and jobs created. Over R1 billion has been invested in innovative technologies and more than 3 000 jobs created in South Africa (SPII, 2013).

3.2.6 Industrial Policy Action Plans

The implementation of the National Industrial Policy Framework, which was adopted in January 2007 and which sets out government's policy on industrialisation, is captured in a series of Industrial Policy Action Plans (IPAPs). The IPAPs represent an integral part of the NGP. The first of these, IPAP 1, was released in August 2007 and since then there have been a number of updates. The IPAP 2 for the period 2010/11 – 2012/13 was the first to address a revised three-year planning period. In March 2013, IPAP 2 for the period 2013/14 – 2015/16 (the dti, 2013a) was released.

The first IPAP was focused on solar water heating. The 2011 revision was broadened to cover, *inter alia*, wind, solar and biomass energy, as well as water and energy-efficient appliances and materials, and waste and waste water treatment and energy and material recovery (the dti, 2011a).

The most recent IPAP 2 includes ambitious plans to boost renewable energy and local manufacturing of green technologies (the dti, 2013a). The central objective of IPAP 2 is the creation of jobs and one of the critical contributors is the support of green industries, renewables and energy efficiency.

Many challenges in the implementation of this plan have been identified, including the need for coordination across government departments and state entities. One such setback was the decision by the National Energy Regulator of South Africa (NERSA) to reduce the renewable energy feed-in tariff (REFIT) to procure electricity from independent power producers (IPPs) and thus significantly impacting the viability of many alternative energy schemes and compromising the attainment of the renewable energy targets in the Integrated Resource Plan (IRP) 2010 (DoE, 2011a).

3.2.7 National Development Plan

The NDP was released by the National Planning Commission (NPC) in November 2011. It followed closely after the diagnostic report, published in June 2011, which outlined the achievements and challenges of South Africa since 1994. In addressing South Africa's development challenges, the NDP placed great emphasis on the need to ensure environmental sustainability and the role of green products and services in contributing to the creation of jobs, the alleviation of poverty and an equitable transition to a low-carbon economy (NPC, 2011).

Key points made in the NDP with respect to transitioning to a low-carbon economy include the need to invest in skills, technology and institutional capacity; the introduction of a carbon price; the need to create greater consumer awareness; and the development of green products and services that will contribute to job creation in niche areas where South Africa has or had the potential to develop competitive advantage (NPC, 2011). Specific mention was made of a target of five million solar water heaters (SWHs) by 2030, the introduction of vehicle emission standards, plans for zero-emission building standards by 2030, and plans to simplify the regulatory regime to facilitate contracting for 20 000 MW of renewable energy by 2030.

3.2.8 Green Economy Accord

The Green Economy Accord (EDD, 2011a) was signed by the South African government and its partners from organised labour, business and civil society in November 2011. It represents an agreement under the overarching framework of the NGP. It is a collective commitment of 18 different ministries to the green economy. There is a recognition that the green economy is founded on new economic activities, that the goal is to create at least 300 000 new jobs by 2020 and that the green economy must address the needs of women and youth, and provide broad-based black economic empowerment.

A number of opportunities based on current technologies were identified, however, the Accord also mentioned the role of innovation and the requirement for capital and investment to bring new technologies to market. The need for a localisation strategy that would assist in creating local industrial capacity, local jobs and local technological innovation was also highlighted.

Finally, a number of specific commitments were made, including the roll-out of one million solar-water heating systems by 2014/15; increasing investments in the green economy; procurement of renewable energy as part of the energy generation; promotion of biofuels for vehicles; clean-coal initiatives; promoting energy efficiency; waste-recycling; reducing carbon emissions in the transport sector; and electrification of low-income communities.

3.2.9 South Africa's Green Economy Summit

In response to the United Nations' call for a Global Green New Deal, the Department of Environmental Affairs and Tourism (DEAT)[2] convened a Green Economy Summit in May 2010 to pave the way for the formulation of a Green Economy Plan. The Summit aimed at catalysing efforts towards a resource efficient, low-carbon and pro-employment growth path (DEAT, 2010).

Based on the Green Economy Summit, the DEAT requested UNEP to commission the South African Green Economy Modelling Report (SAGEM), which "aimed at assessing the impacts of green economy investments in selected sectors pertaining to the South African economy" (UNEP, 2013).

3.2.10 National Climate Change Response Policy

The 2004 National Climate Change Response Strategy represented the first direct recognition of the need for action on climate change. Two years later, the Cabinet commissioned the Long-term Mitigation Scenario study in an attempt to produce sound scientific analysis from which the government could derive a long-term climate policy. The study produced a series of policy recommendations. In July 2008, the Vision, Strategic Direction and Framework for Climate Policy were announced. The current flagship policy in South Africa is the National Climate Change Response Policy (NCCRP), approved by Cabinet in October 2011 (DEAT, 2011b). This policy's White Paper presents the South African government's vision for an effective climate change response and the long-term, just transition to a climate resilient and lower carbon economy and society. It reflects a strategic approach referred to as "climate change resilient development", addressing both adaptation and

[2] The new name of this ministry was announced on 25 May 2014 as the Department of Environmental Affairs (DEA). However, all of the publications and activities mentioned in this report are those of the previous ministry, the Department of Environmental Affairs and Tourism (DEAT).

mitigation. The White Paper accepts the conclusions of the Intergovernmental Panel on Climate Change (IPCC); regards climate change as one of the greatest threats to sustainable development; reaffirms its commitment towards the UNFCCC and the Kyoto Protocol, and undertakes to develop a comprehensive national response plan of which the White Paper is an integral part.

South Africa's response to climate change is organised around two major objectives:

(1) Managing the inevitable impacts through building resilience and emergency response capabilities.

(2) Making a fair contribution to global efforts to stabilise GHG concentrations in the atmosphere, in order to prevent dangerous anthropogenic interference with the climate system, and within an appropriate timeframe.

Under the UNFCCC and its Kyoto Protocol, South Africa is committed to reduce its GHG emissions by 34% (by 2020) and 42% (by 2025) below its 'business as usual' (BAU) emissions growth trajectory. This commitment is contingent (in accordance with Article 4.7 of the UNFCCC) on the extent to which developed countries meet their own commitments to provide financial, capacity-building, technology development and transfer support to developing countries, including South Africa.

Accordingly, the NCCRP defines as a strategic goal the need to "prioritise cost-effective and beneficial mitigation policies, measures and interventions" that lead to a reduction in emissions below the country's BAU trajectory as measured against a benchmark "peak, plateau and decline" GHG emission trajectory – where GHG emissions peak between 2020 and 2025, plateau for approximately a decade and then begin declining in absolute terms (DEAT, 2011b).

Adapting to climate change and making the transition to a much less carbon-intensive economy will require massive changes. Investments in green technologies will be essential to achieving the envisaged objectives of the NCCRP.

3.2.11 National Skills Development Strategy

The National Skills Development Strategy (NSDS III) was introduced in 2011 as an overarching strategy to guide skills development over the period 2011 to 2016 (DHET, undated). Although it does not specifically mention green technologies, it states that priorities that will take precedence in the National Skills Fund include skills to support the green economy.

3.3 Sector-based National Policies driving Green Technologies

3.3.1 Energy

The policy environment is dominated by policies in the energy sector, some of which are highlighted below.

3.3.1.1 Renewable Energy White Paper

An earlier White Paper on Energy Policy published in 1998 set out national policy on supply and consumption of energy, but failed to set targets for a contribution from renewable energy. Consequently, a separate White Paper on Renewable Energy aimed at promoting renewable energy development was published in 2003. It set a target of 10 000 GWh of renewable energy contribution to energy consumption by 2013. It was to be made up of contributions from biomass, wind, solar, small-scale hydro and biofuels, and would comprise about 4% of projected electricity demand by 2013 (DME, 2003). However, until recently, there has been poor implementation, largely as a result of a lack of an implementation plan and poor capacity in the Department of Energy (DoE) (Trollip and Marquard, 2010). At the time of writing this report, in terms of implemented renewable energy capacity, less than 10% has been achieved (Trollip and Marquard, 2013).

3.3.1.2 National Energy Efficiency Strategy

The National Energy Efficiency Strategy (NEES) of 2005 (DME, 2005) follows from the White Paper on Energy Policy published in 1998. It sets a national target for energy efficiency improvement of 12% by 2015 as measured against the projected BAU increase in energy use, thereby aiming to retard the rate of increase in energy use rather than to reduce energy demand. Included in the strategy were sector-based targets ranging from 15% for the Industrial and Mining sector, the Power Generation sector and the Commercial and Public Building sector, to 10% for the Residential sector and 9% for the Transport sector. The NEES was reviewed in 2008 and again in 2011, although the latest revision was only approved by Cabinet in 2012. Targets were not revised as the current cycle of the NEES is due to end in 2015. The second review made recommendations that will be implemented through the National Energy Efficiency Action Plan in the period leading up to 2015 and post-2015.

According to Nassiep (2013), there is a lack of an adequate data repository on energy efficiency to facilitate measurement of progress in this regard and some proposed interventions have not materialised.

One of the outcomes of the 2005 NEES was a voluntary Energy Efficiency Accord between the Department of Minerals and Energy (DME) and major industrial users and industrial associations which commits signatories to the development of an energy efficiency strategy. Initially, there were 30 signatories and currently there are 59. The Accord (now referred to as the Energy Efficiency Leadership Network) is facilitated by the National Business Initiative (NBI). In an assessment undertaken in 2008 (DME, 2008), it was shown that almost 2 500 GWh of electricity, equivalent to 3.5 days of average national electricity demand at the time, was saved by only 15 signatories who were able to report. The overall conclusion of the initiative's role was positive and many recommendations for continuous improvement were made (DME, 2008).

A number of other regulations are aligned with NEES and assist with implementation. These include the Income Tax Allowance on Energy Efficiency Savings regulations that target large companies; National Building Codes and Regulations; and Minimum Energy Performance Specifications for household electrical appliances.

3.3.1.3 Amended Electricity Regulation Act

The Amended Electricity Regulation Act of 2006 has as one of its objectives the promotion of the use of diverse energy sources. Within the Act, the Minister of Energy, in consultation with the NERSA, may determine the sources, as well as the mix of energy sources from which electricity may be generated (RSA, 2006). However, there are some shortcomings; for example, the Act does not provide an incentive for municipalities to diversify the sources from which they generate electricity, or to generate electricity themselves.

3.3.1.4 Biofuels Industrial Strategy

The first version of the Biofuels Industrial Strategy was released in 2007 (DME, 2007). The overall aim was to contribute up to 50% of the national renewable energy target of 10 000 GWh. This would be achieved through a biofuels average market penetration of 2% of liquid road transport fuels, i.e. petrol and diesel, by exploiting the biomass resources potential of the country and secondly, by introducing mandatory blending, which was gazetted in 2012 for implementation in 2015 (DoE, 2013a).

In January 2014, the DoE published its draft position paper on the South African Biofuels Regulatory Framework for public comment. The paper is aimed at creating a regulatory environment that is conducive to the production of biofuels, bearing in mind that the 2009 strategy has not yielded the results expected. Amongst the incentives is a mandatory blending regulation, requiring 5% biodiesel in diesel and between 2% – 10% bioethanol in petrol, due to come into effect in October 2015, but now delayed until October 2017. The framework also provides financial incentives to biodiesel manufacture (De Bruyn, 2014).

3.3.1.5 National Energy Act

The National Energy Act (*Act 34 of 2008*) is the core legislation governing energy in South Africa. Although not directly related to the introduction of green technologies in the energy sector, the fact that it supports a mix of diverse energy sources provides an enabling environment for green renewable energy technologies. The Act states, *inter alia*, that increased generation and consumption of renewable energy will be an important contributing factor towards attaining the objective of promoting sustainable development in South Africa.

3.3.1.6 Ten-year Innovation Plan

In 2008, the DST adopted a Ten-year Innovation Plan, Innovation Towards a Knowledge-based Economy 2008 – 2018 (DST, 2008). The plan identifies five Grand Challenges, one of which is Energy Security. Specific mention is made of renewable energy, clean coal technologies and the hydrogen economy. It is therefore to be expected that there will be an investment in research in these areas and a greater likelihood of innovation in these fields.

3.3.1.7 Renewable Energy Feed-in Tariffs and Renewable Energy Bids

In an attempt to kick-start the renewable energy industry in South Africa, renewable energy feed-in tariff (REFIT) guidelines were published in March 2009 by NERSA, specifying the rates that IPPs would be paid for electricity generated from renewable energy sources (NERSA, 2009a). However, two years after having announced REFIT rates, there were still no power purchase agreements (PPAs) that had been made available to developers by Eskom. The slow early start can be attributed to the problem of having a single, dominant conventional energy company, namely Eskom, as the system operator (Trollip and Marquard, 2010; Eberhard, 2013) and uncertainty in REFIT rates, which were revised downwards by NERSA in 2011 (NERSA, 2011).

A dramatic shift was needed to improve the implementation of renewable energy. In July 2011, the DoE announced that REFIT rates were to be replaced by a competitive bidding process known as the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP). Renewable energy bids (REBID) would be managed by the National Treasury as opposed to NERSA.

Despite the considerable early uncertainty that was created by this policy switch, Eberhard (2013) has expressed confidence in the new approach, suggesting that it may offer lessons for other developing countries.

It has stimulated considerable interest from the private sector, has been competitive, has attracted international investment and has been implemented in record time. Under this new scheme, there have been three bidding rounds. In the first phase 1 415.5 MW capacity was allocated and in the second phase, 1 043.9 MW (Table 3.2).

In early 2012, it was also confirmed, although not through a formal announcement, that municipalities would be allowed to enter into their own contractual agreements to procure renewable electricity.

Although it is a little premature to report success of the REBID programme as most projects still have to achieve commercial operation, the scheme has been successful in terms of attracting private investors (Eberhard, 2013) and certainly has given a significant boost to the green technology industry in South Africa. A key success factor included the positioning of the REIPPPP in the Public-Private Partnership Unit in the National Treasury which was able to involve local and international advisors to assist in running a complex bidding process.

Table 3.2: Analysis of REIPPPPallocations and planned allocations

Technology	Total MW Allocation Planned	MW Capacity Allocated in First Bid Submission Phase	MW Capacity Allocated in Second Bid Submission Phase	MW Capacity Allocated in Third Bid Submission Phase	MW Capacity Allocated in Future Bid Submission Phases
Onshore Wind	1 850.0	634.0	562.5	787.0	1 336.0
Solar Photovoltaic	1 450.0	631.5	417.1	435.0	1 041.0
Concentrated Solar Power	200.0	150.0	50.0	200.0	200.0
Small Hydropower					
(≤ 10MW)	75.0	0.0	14.3	0.0	121.0
Landfill Gas	25.0	0.0	0	18.0	7.0
Biomass	12.5	0.0	0	16.0	43.0
Biogas	12.5	0.0	0	0.0	60.0
Total	**3 625.0**	**1 415.5**	**1 043.9**	**1 456.0**	**2 808.0**

Source: http://www.ipp-renewables.co.za

3.3.1.8 Electricity Regulations on New Generation Capacity

The electricity regulations on new generation capacity passed in 2009 apply to all technologies, including renewable energy (NERSA, 2009b). Their main aim is to regulate the entry of a buyer and an IPP through a power purchase agreement (PPA), or a contract between the producer and the purchaser of power. An example is the PPA between Darling Wind Power (Pty) Ltd and the City of Cape Town that buys the electricity generated by the wind farm. The electricity is then offered, for sale, to customers within the municipality who are in the market for 'green' electricity.

3.3.1.9 Integrated Resource Plan for Electricity

The Integrated Resource Plan (IRP) is a medium to long-term electricity plan that guides the expansion of electricity supply (DoE, 2011a); the appropriate timing and mix of technologies to meet the supply; and takes into account the influence of other factors such as water, transmission infrastructure, skills, etc. It is an important document as it forms the basis on which NERSA will license projects.

The IRP (2010), which was promulgated in May 2011, projects an almost doubling of electricity capacity by 2030 (DoE, 2011a). A total of 33% of new generation is anticipated to come from renewable energy. It includes plans for 8 400 MW of new wind generation, 8 400 MW of new PV generation and 1 000 MW of concentrated solar power (CSP) over the period 2010 to 2030. Notwithstanding the criticism from some quarters that these targets are too low, there is unequivocable support for renewable energy as part of South Africa's energy mix into the future and hence green growth. There are also plans to improve energy efficiency and to reduce emissions.

It was noted in the ASSAf commentary on the IRP 2010 (ASSAf, 2011a) that the targets for electricity from renewable resources were out of alignment with public pronouncements about a 5 000 MW solar plant to be built in the Northern Cape. Bearing in mind that all new generation capacity must be specified in the IRP 2010 in order to be licensed, the status of the announcement is unclear. The cost for the proposed solar plant (R150 million) is also substantially lower than solar costs used in the IRP 2010 and international costs (Trollip and Marquard, 2010).

The roll-out of the renewable energy commitment is being initiated through the REIPPPP through a series of bidding rounds. There are significant opportunities for foreign investment in the country, but also the development of the local renewable energy industry. The dti has the responsibility for setting local content targets and monitoring progress through the IPAPs. It is intended that local content targets will increase with every bidding round.

There has also been much criticism of the IRP (2010), for example Trollip and Tyler (2011) who argue that the electricity demand forecasts are based on confidential information within Eskom and that there is a lack of alignment with policy documents such as the IPAP or NEES.

The IRP is intended to be reviewed every two years as new information and data become available. An IRP update has recently been published (DoE, 2013b). Although the IRP (2010) is still the official plan, the update attempts to take into account significant changes that have taken place over the last three years, in particular the aspirations of the NDP. The 2030 electricity demand has been revised downwards; the nuclear decision has been delayed; and additional renewable energy capacity announced, specifically 1 000 MW of PV, 1 000 MW of wind and 200 MW of CSP. Although the targets for renewable generation are noteworthy, the IRP lacks a solid monitoring and evaluation strategy that can track these targets and measure their performance. Without a commitment to monitoring these targets, it is uncertain whether they will be met.

3.3.1.10 South African Renewables Initiative

The South African Renewables Initiative (SARi) was launched at the UN 17th Conference of the Parties (COP 17) climate change conference in Durban in 2011 (the dti, 2011b). It seeks to stimulate the growth of the local renewable energy industry through an international financing scheme for South African renewable energy projects and industries. It is anticipated that it will make a significant contribution to boosting the green economy and in assisting South Africa to meeting the country's emission reduction targets of 34% below BAU by 2020 and 42% by 2025 as announced at the COP 16 meeting in Copenhagen.

The SARi could potentially increase the contribution of renewables in the energy mix above the 17 800 MW specified in the IRP (2010) and could also create approximately 40 000 green industry jobs (the dti, 2011b).

3.3.1.11 Solar and Wind Sector Development Strategy

Investment in renewable energy applications is clearly signalled in the IRP 2010 and the proposed allocation to solar and wind energy provides an opportunity for localisation of products and services in these sectors. In response, the dti published its Solar and Wind Sector Development Strategy in May 2012 (the dti, 2012). Its vision is to establish a local renewable energy manufacturing sector in South Africa that would supply both final products and components in the solar and wind sectors. The strategy, which was approved in May 2012, identified seven key action programmes: market facilitation, local manufacturing and industry upgrading incentives, local content requirements, technical and physical infrastructure, trade and investment support and facilitation, research demonstration and skills development (the dti, 2012).

The localisation potential of CSP, PV and large and small-scale wind is addressed, as well as potential for investment, job creation and local economic development. All this is considered in the context of South Africa's renewable energy resource and state of R&D in the country. Finally, key action plans for government to support the wind and solar power industry are outlined.

3.3.1.12 Department of Energy's 2012 Strategic Plan

The Department of Energy's (DoE) approved 2012 strategic plan for the next three years has set a national energy saving target of 20 TWh from implemented energy efficiency and demand-side management (EEDSM) measures across all sectors including the public sector.

3.3.1.13 Electric Vehicle Industry Road Map Initiative

In an attempt to stimulate the electric vehicle industry in South Africa, the dti, in collaboration with the DEAT, launched the Electric Vehicle Industry Road Map Initiative in 2013. The initiative aims to stimulate demand for electric vehicles through various incentive schemes, to increase public awareness, to support R&D, and to stimulate investment in local electric vehicle-manufacturing and to plan for the provision of the necessary infrastructure, such as charging stations (the dti, 2013b).

3.3.1.14 Working for Energy Programme

Designed as a social upliftment programme, this initiative aims to improve access of people living in rural and peri-urban areas to simple, low-carbon energy technologies (Nassiep, 2013). Most of the projects are related to biomass and solar energy. It specifically targets youth, women and people with disabilities.

3.3.1.15 Independent System and Market Operator Bill

This bill, which is currently under consideration, aims to establish the Independent System and Market Operator (ISMO) as a company responsible for the planning of the electricity supply by electricity generators through the national transmission system, electricity dispatch and aggregation in respect of the sale of electricity. The ISMO is intended to act as the buyer of electricity from the generators in South

Africa, and also a seller to its customers, and should do so in a manner that minimises the overall cost of electricity to customers (DoE, 2011b). The bill is not clear, at this stage, as to how the ISMO will interact with, for example, municipalities and heavy industry, especially those that, at times in future, may be net suppliers of electricity.

3.3.2 Water

3.3.2.1 National Water Act

The National Water Act (NWA) (*Act 36 of 1998*) is the primary legislation pertaining to the regulation of water in South Africa and aims to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled sustainably.

3.3.2.2 National Services Water Act

The National Water Services Act (*Act 108 of 1997*) operates in tandem with the NWA. Its objectives include the right of access to basic water supply and the right to basic sanitation necessary to secure sufficient water and an environment not harmful to human health or well-being; and the promotion of effective water resource management and conservation amongst others.

There is a drive to merge the legislation governing water services and water resources to facilitate government objectives, including equitable access to water (DWA, 2013).

3.3.2.3 National Water Resource Strategy

In accordance with the NWA, a National Water Resource Strategy (NWRS) was released in September 2004. A second National Water Resource Strategy (NWRS2) was published in 2013. It aims at ensuring "that national water resources are protected, used, developed, conserved, managed and controlled in an efficient and sustainable manner towards achieving South Africa's development priorities, in an equitable manner" (DWA, 2013). The NWRS2 places a strong emphasis on the water energy connection and one of the objectives is to promote the optimal development of hydroelectricity generation.

3.3.3 Waste

The waste sector in South Africa is guided by a number of key pieces of legislation that provide the basis for green technologies to contribute to waste minimisation, reuse and recycling. An overview of the various acts and international agreements is provided by DST (2012), with the primary policies governing waste management summarised briefly here. It is noted that successful implementation of the goals contained in the national policies often depends on translation into municipal by-laws.

3.3.3.1 White Paper on Integrated Pollution and Waste Management Act

The White Paper on Integrated Pollution and Waste Management for South Africa written in 1998 (RSA, 2000) provides a broad framework for integrated waste management. It introduced the principles of 'cradle-to-grave' and 'polluter pays'.

3.3.3.2 National Environmental Management: Waste Act

The National Environmental Management: Waste Act (NEM:WA) of 2008 (RSA, 2009b) is the primary piece of legislation governing waste management in South Africa. It introduced the concept of the 3Rs: reduce, recycle and re-use for the first time.

3.3.3.3 National Environmental Management: Waste Amendment Act

The National Environmental Management: Waste Amendment Act (NEM:WAA) of 2014 (RSA, 2014) sets out amendments to the Waste Act, particularly relating to certain definitions, including the definition of "waste"; the drafting of a pricing strategy to guide the implementation of economic instruments in the waste sector; establishment of the Waste Management Bureau; and transitional provisions in respect of existing industry waste management plans.

3.3.3.4 National Waste Management Strategy

The National Waste Management Strategy (DEAT, 2011c) specifies eight goals to be achieved by 2016, many of which provide an enabling framework for the development and implementation of green technologies. Examples include Goal 1 – Promote waste minimisation, re-use, recycling and recovery of waste; Goal 3 – Grow the contribution of the waste sector to the green economy; Goal 5 – Achieve integrated waste management planning; and Goal 7 – Provide measures to remediate contaminated land.

3.3.4 Buildings

Policies that address buildings directly are summarised below.

3.3.4.1 National Building Regulation and Building Standards Act

The National Building Regulation and Building Standards Act (*Act 103 of 1977*) sets standards and regulations for energy efficiency in buildings. In November 2011, an amendment to the act stated that all new buildings and extensions to existing buildings have to meet standard energy efficiency regulations (Botes, 2011).

3.3.4.2 National Framework for Green Buildings

The National Framework for Green Buildings of 2011 aims to enunciate South Africa's national vision for sustainable building and construction and indicates strategic interventions to recalibrate the South African construction and property industries.

3.3.4.3 Innovative Building Technology Implementation Plan

The Innovative Building Technology (IBT) Implementation Plan of 2013 aims to advance the uptake of innovative building technologies in South Africa and creates a set-aside of government investment in social infrastructure construction for IBT.

3.3.5 Information and Communication

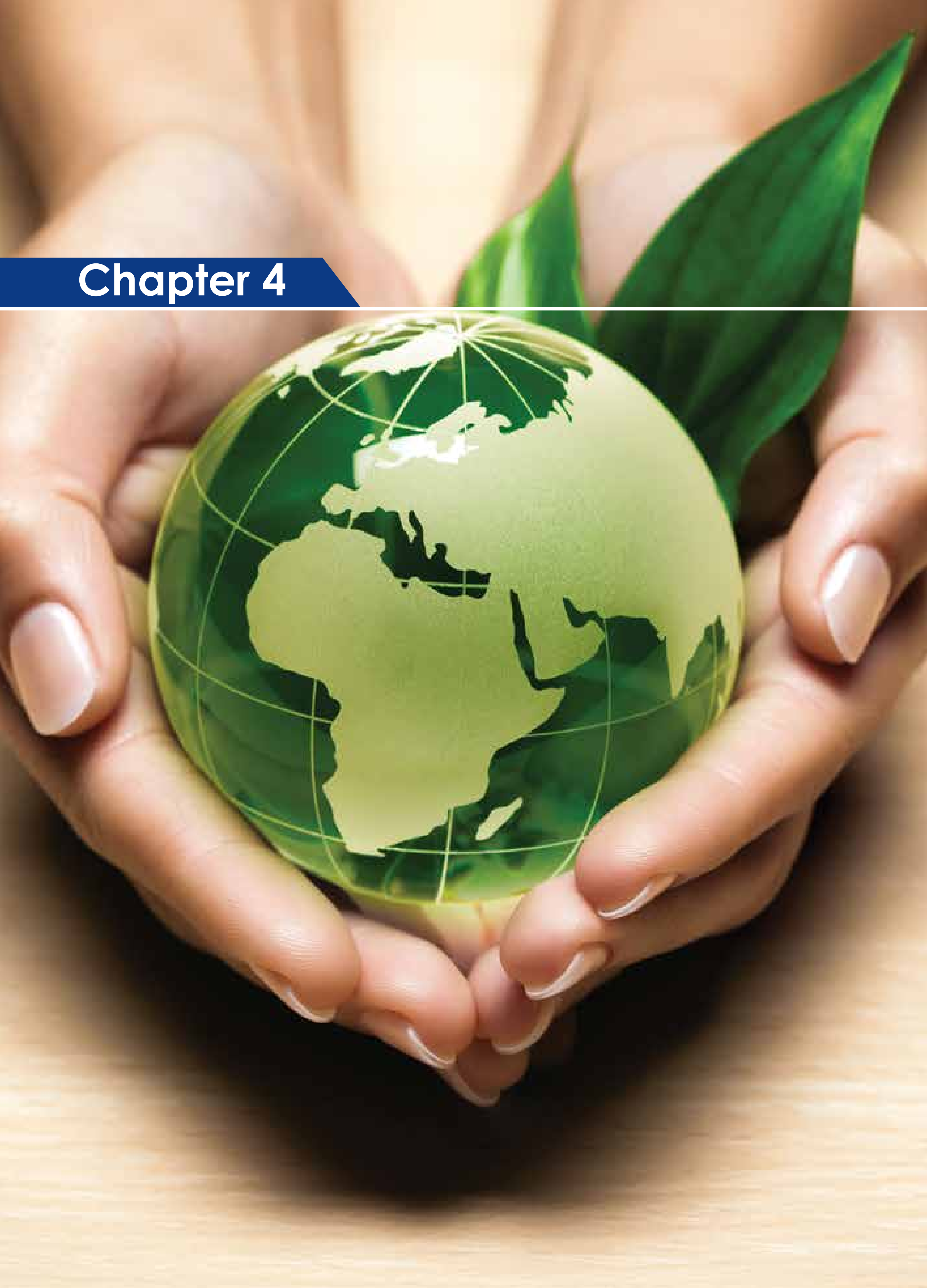
The Information and Communication Technology (ICT) R&D and Innovation Strategy for South Africa was introduced in 2007 (DST, 2007b). Although there is no mention of ICT's contribution to green technologies, an enabling framework for the advancement of ICT R&D and innovation is established.

The ICT Research, Development and Innovation Roadmap, developed by the DST, was approved by Cabinet in May 2013 and is in the process of implementation. One of the clusters is sustainability and the environment, which includes green ICT.

3.4 Concluding Remarks

While this chapter has highlighted only the most pertinent laws and policies, it is clear that South Africa has no shortage of policies that address green technologies, either in a direct or indirect manner. The challenge, as will be seen later, is to ensure policy co-ordination amongst the various sectors.

Chapter 4



4 INTERNATIONAL PERSPECTIVES ON GREEN TECHNOLOGY DRIVERS

4.1 Introduction

The aim of this chapter is to provide some further international context for the analysis of the current status of, and future priorities for, green technologies in South Africa. It starts by summarising global trends in green technologies in the energy, water, sanitation and waste sectors. The chapter draws on some of the available indicators of green innovation and its impacts. Next, some considerations for countries that are seeking to learn lessons from international experience are set out. This focuses on technology and industry 'catching up' strategies that have been pursued by some developing countries, and the role of technological capabilities and policy frameworks in these strategies. This discussion is followed by case studies of two countries that have had particularly strong 'green growth' strategies, *viz.* Germany and South Korea. A detailed discussion of the strategies of each country is included in Appendix 3.

4.2 Global Trends in Green Technology

There are a number of proxy indicators that can be used to analyse patterns of innovation in green technologies. Given the systemic, long-term and uncertain nature of innovation processes, such indicators can only provide a partial picture of these patterns. In addition to this, data availability is sometimes inadequate. Changes in the structure of many industrialised economies over time, and the increasing importance of globalisation, mean that some indicators may become less useful over time.

Despite well-documented drawbacks (e.g. Freeman and Soete, 2009), efforts to analyse innovation often focus on input measures, particularly levels of research, development and demonstration (RD&D) funding devoted to technology development by the public and private sectors. Data on public funding – especially in Organisation for Economic Co-operation and Development (OECD) countries – are more readily available than data on private sector funding for RD&D. These indicators are sometimes complemented by indicators of innovation outputs, particularly patents. Patent data need to be handled with care, given that raw data on patent applications are a poor guide to the quality or impact of those patents. In addition, the importance of patents for innovation varies between technologies, firms, sectors and countries.

In addition to these traditional indicators, innovation outcomes can also be represented using indicators, such as rates of deployment of new technologies or trends in technology costs. Taken together, these indicators can provide a useful starting point for understanding broad trends in green technology innovation patterns on a national, sectoral or global basis.

4.2.1 Green Energy Technologies

Shifting towards more sustainable, low-carbon energy systems is centrally important in the transition to a green economy. Low-carbon energy supply technologies and more efficient energy technologies have been promoted in many countries through government policies and private sector investments. Government spending on energy-related RD&D by International Energy Agency (IEA) member countries has increased since the late 1990s (Figure 4.1). Among these technologies, nuclear energy has historically accounted for the largest share of spending, although this share has gradually decreased in the last 40 years. Spending on renewable energy and energy efficiency technologies has increased rapidly in the last ten years. In the BRICS countries and Mexico, spending on energy RD&D has also increased. China had the largest spending on energy RD&D in 2008, representing about one third of the total spending in IEA member countries.

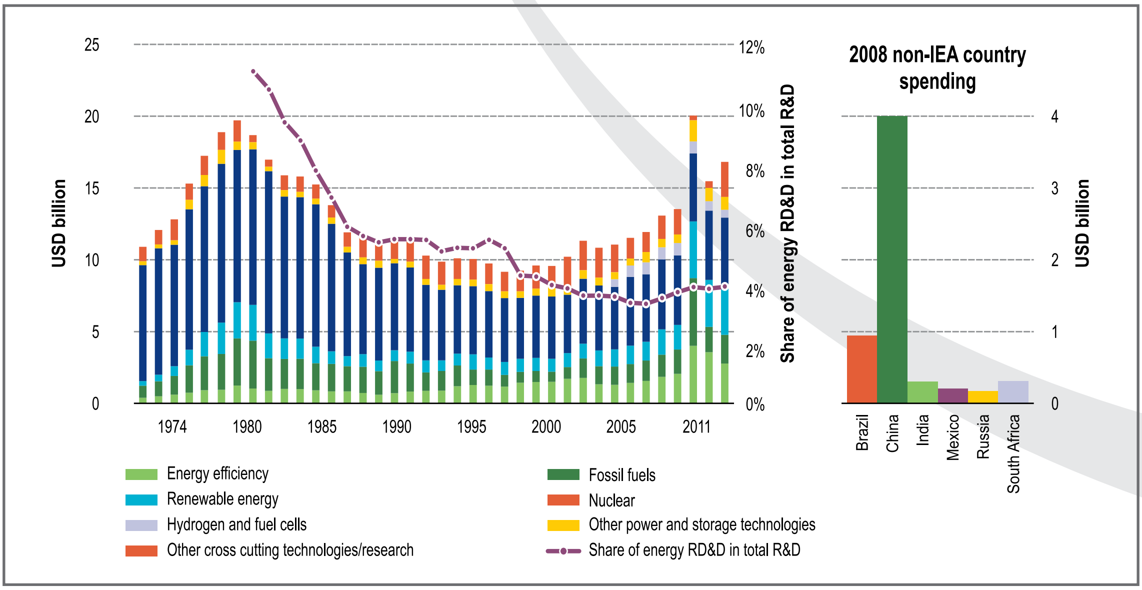


Figure 4.1: Government energy RD&D expenditure in IEA member countries (IEA, 2013)

This increase in RD&D has mirrored a rise in the number of patent applications for cleaner energy technologies. Between 1999 and 2008, the number of patented inventions in renewable energy increased by 24%. In comparison, patents for electric and hybrid vehicles and energy efficiency in building and lighting increased by 20% and 11% respectively, more rapidly than the rise of total patent applications which was 6% (OECD, 2011a). These figures also show that technology development and patenting is concentrated in a small number of countries (Figure 4.2). Despite the increase in RD&D spending in emerging countries, companies and other organisations based in OECD countries still hold a majority of patents in clean energy technologies. For example, in 2008, the number of patent applications by Japan, the United States of America (USA) and Germany accounted for more than half of the world's total applications. Japan's patent applications were relatively more focused on the area of energy-efficient buildings and lighting. The USA's applications were concentrated in innovation related to renewable energy. Both Germany and South Korea's applications were also largely concentrated in renewable energy.

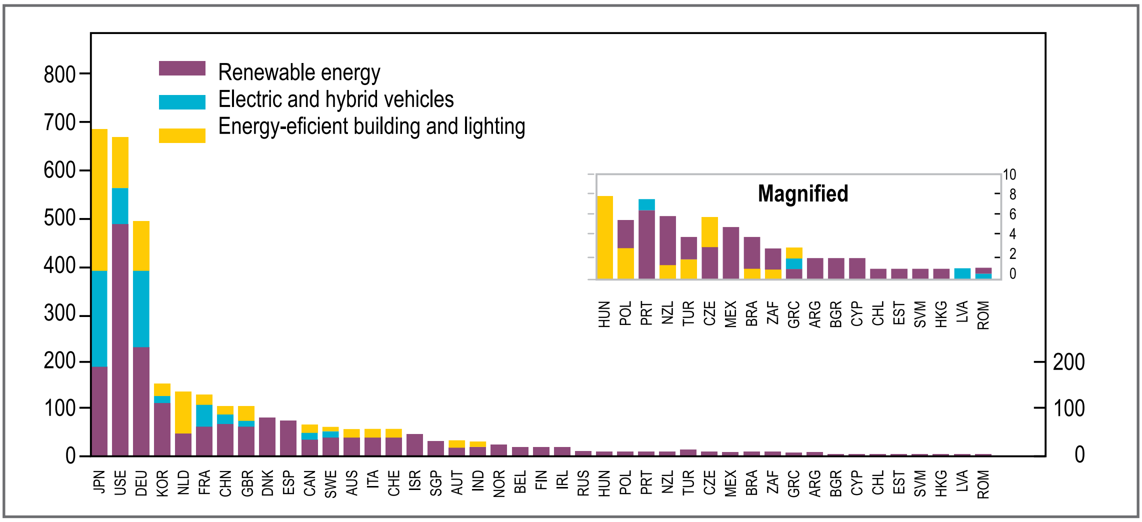


Figure 4.2: Patent applications at the Patent Co-operation Treaty, 2008 (OECD, 2011a)

Figure 4.3 shows the longer-term trend in patent applications for a number of specific cleaner energy technologies. The number of low-carbon technology patents filed grew four-fold between 1980 and 2008, reflecting increases in RD&D spending, as well as significant demonstration and deployment policies in several countries. Since 2000, the patents filed for wind power and solar PV have increased sharply. The number of CCS-related patent applications increased at an annual growth rate of 23% over the period 2000 – 2011, and by 45% between 2006 – 2011(IEA, 2013).

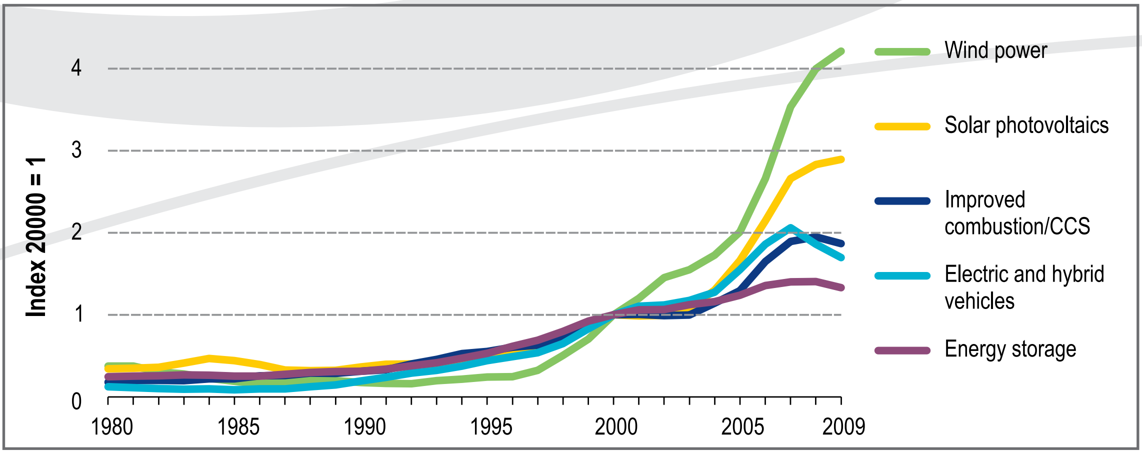


Figure 4.3: Annual growth rate of low-carbon technology patenting (IEA, 2013)

There is significant evidence that this rapid increase in RD&D and patenting in cleaner energy supply technologies is starting to have an impact on the global technology mix. According to the BP Statistical Review of World Energy, renewable energy used in power generation increased by 15.2% between 2011 and 2012, building on many years of growth. Wind energy accounted for more than half of this renewable power generation growth, whilst solar power generation grew by 58% (BP, 2013). Global hydroelectric output also increased, with China accounting for all of the net increase. Hydroelectric output accounted for 6.7% of global energy consumption in 2012, the highest share on record (BP, 2013). By contrast, biofuels production in the world saw its first decline since 2000. The share of nuclear power also fell, to 4.5% of global energy consumption. This represented the second consecutive year that nuclear power's contribution has fallen, and is the largest decline on record (BP, 2013). Overall, the share of renewable energy in global energy consumption, including large hydro, is now 8.6%.

Figure 4.4 shows the renewable consumption and renewable share of power generation by region. It is clear that OECD countries have a higher renewable share than non-OECD countries. Europe and Eurasia's deployment of renewable energy in power generation has been growing rapidly since 1992. In contrast, the Middle East has the lowest rate of using renewable energy in power generation.

Turning to trends in new investment in low-carbon energy technologies, total investment for renewable power and fuels (including small hydroelectric projects) in 2012 was $244 billion. China was the dominant country with $67 billion of investment in renewable energy, rising by 22% from the previous year (Frankfurt School-UNDP Centre and BNEF, 2013). Several other emerging countries also saw sharp increases in investment, including Morocco, Mexico, South Africa and Chile.

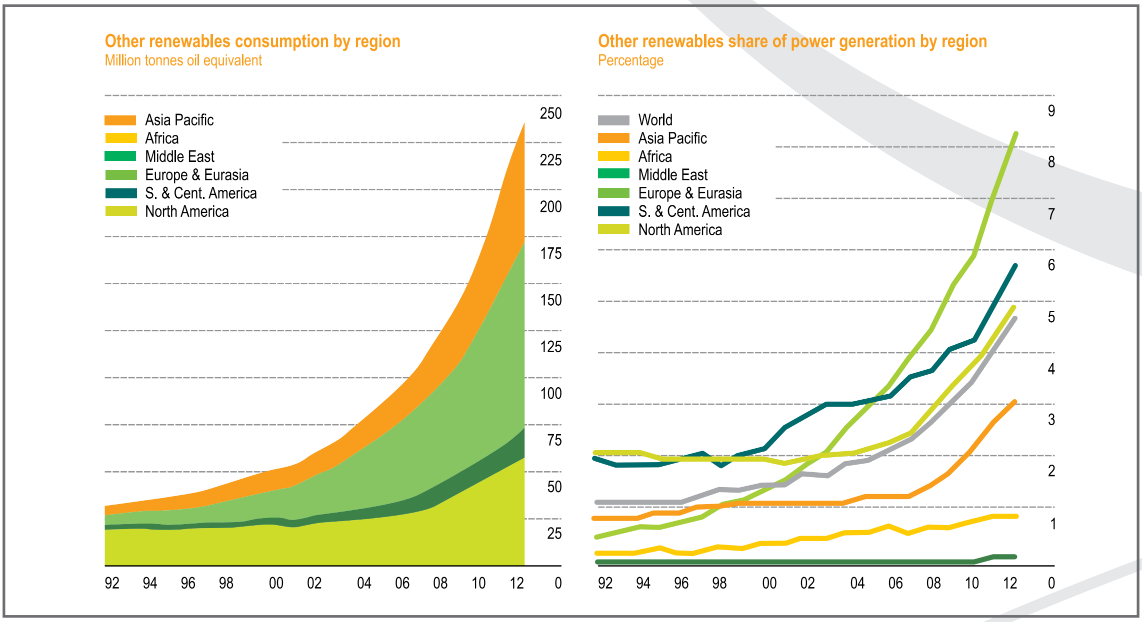


Figure 4.4: Renewable consumption and renewable share of power generation by region (BP, 2013)

On the demand side, energy efficiency plays an important role in restraining demand growth and energy costs, and in mitigating climate change. It can be implemented quickly compared with some energy supply investments, and is one of the cheapest options for large-scale CO_2 abatement. Therefore all major energy-consuming countries have introduced new legislation on energy efficiency (IEA, 2012b). In order to measure energy efficiency's impact, energy intensity is widely used as a popular indicator. This has shortcomings as it fails to distinguish the effects of factors such as changes in the structure of a country's economy or its climate (IEA, 2012b).

Energy intensity is defined as the ratio of energy used to gross domestic product (GDP). Figure 4.5 shows energy intensity trends by region for the period 1980 – 2010. In most areas, it has fallen over the last 30 years, but the rate of decline has slowed down. However, the energy intensity in the Middle East has increased since 1980. This is mainly driven by the region's low energy prices that provide little incentive for the deployment of energy-efficient technologies (IEA, 2012b). Africa's energy intensity went up until 1995, mainly driven by the area's economic development, but since then it has slowly decreased.

It is hard to obtain data for investment in energy efficiency technologies. A recent report by environmental non-government organisation (NGO), the World Wildlife Fund (WWF), suggests that investment in these technologies was approximately 25% of the total investment in renewable energy and energy efficiency technologies in 2011 (Van der Slot and Van den Berg, 2012). Such figures are open to criticism, however, given that judgements about what should be included as energy efficiency investment are likely to be very subjective.

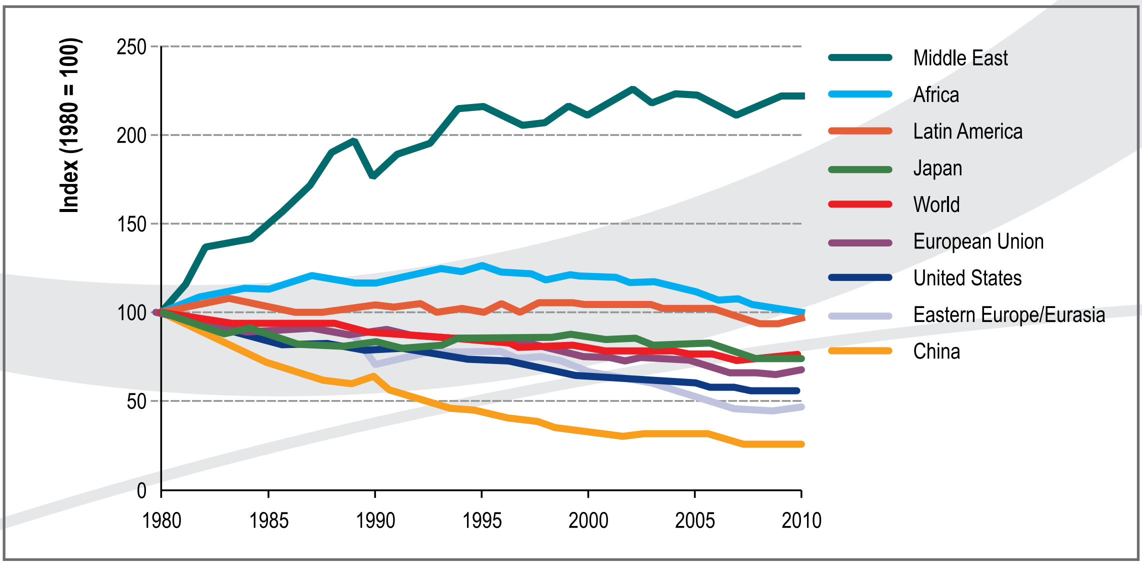


Figure 4.5: Energy intensity trends by region, 1980 – 2010 (IEA, 2012b)

4.2.2 Global Trends in Green Technologies in Water and Sanitation

Water is a fundamental source for human beings on the planet. According to the World Health Organisation (WHO), "inadequate sanitation is a major cause of disease world-wide and improving sanitation is known to have a significant beneficial impact on health, both in households and across communities. The word 'sanitation' also refers to the maintenance of hygienic conditions, through services such as garbage collection and wastewater" (WHO, 2013).

According to the WHO and the United Nations Children's Fund (UNICEF), 768 million people live without access to clean drinking water supplies, most of whom live in rural areas. A total of 2.5 billion lack access to improved sanitation services. Since 1990, almost 1.9 billion people have received access to improved sanitation facilities (WHO and UNICEF, 2013). This means that the world has achieved the Millennium Development Goal (MDG) drinking water target but will not meet the MDG sanitation target if the pace of change in the sanitation sector is not accelerated. Figure 4.6 and Figure 4.7 show global trends in access to fresh drinking water and sanitation facilities respectively.

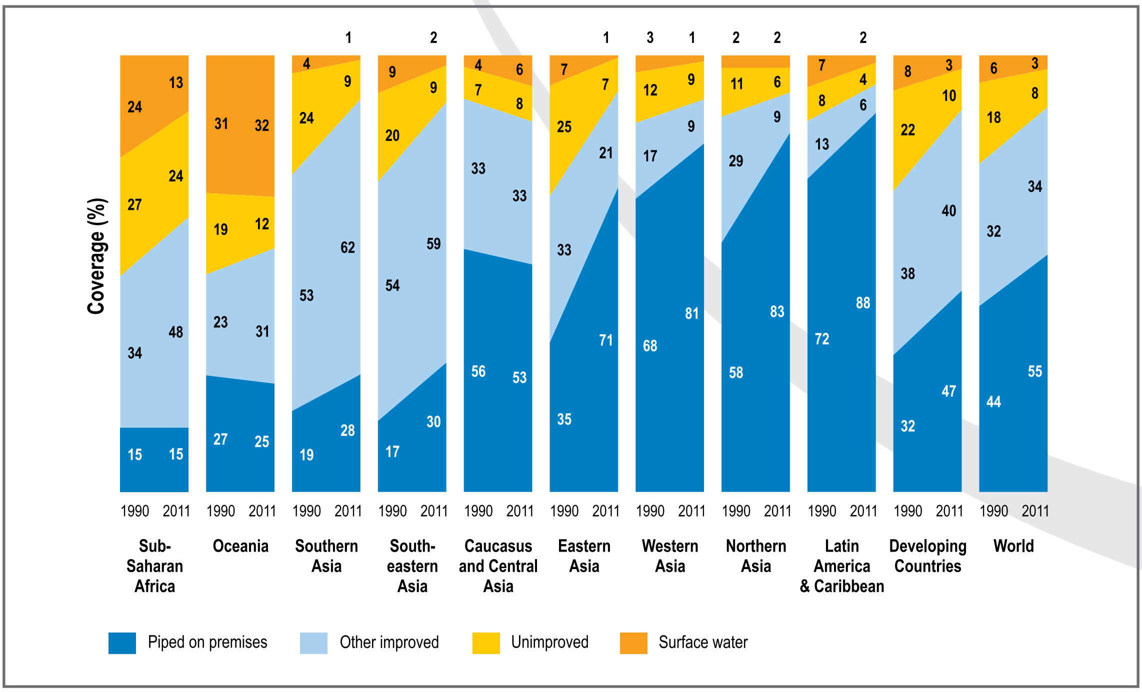


Figure 4.6: Trends in drinking water coverage, 1990 – 2011 (WHO and UNICEF, 2013)

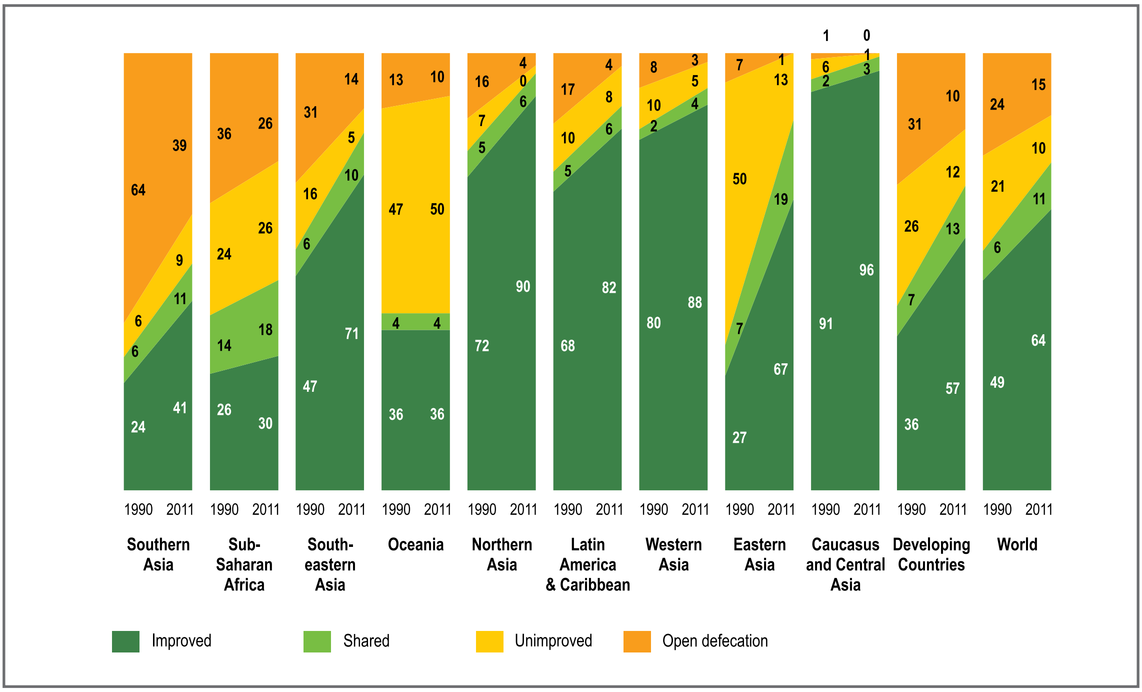


Figure 4.7: Trends in sanitation coverage, 1990 – 2011 (WHO and UNICEF, 2013)

Water security in many countries is deteriorating due to increasing water demand and water pollution. On the demand side, agriculture accounts for around 70% of global freshwater withdrawals; industry and domestic use accounts for about 20% and 10% respectively (UN-Water, 2012). It is estimated that global water demand rose twice as fast as population growth over the last century (OECD, 2012a). However, increasing water supply tends to be costly and difficult, and freshwater sources in the world are already under stress. Historical data show that the government expenditure for upstream water supply (excluding distribution) has been $40 billion to $45 billion per year. As the demand increases, this bill could increase to around $200 billion a year by 2030 (McKinsey Global Institute, 2011). Therefore sustainable management of water resources is a key component for the coming decades and green technologies will play an important role in all stages of water management. This includes water production and treatment, water distribution, efficiency of water usage and waste-water disposal (BMU, 2012).

Specific data on the development of greener technologies for water and sanitation are hard to find. It is possible to get patent data, however, which are a partial and imperfect indicator of green innovation in these sectors. In the last decade, the number of patent applications of water pollution abatement filed under the Patent Co-operation Treaty (PCT) has increased by 70% in the world (Figure 4.8). There was a fall in patenting between 2010 and 2011, which was largely accounted for by patenting patterns in OECD countries outside the EU.

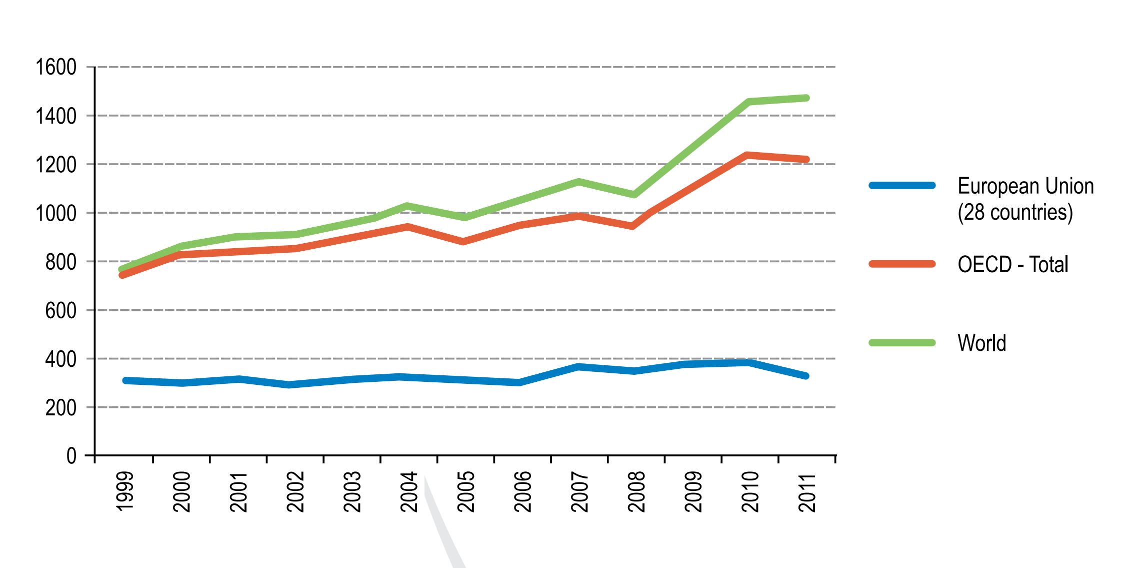


Figure 4.8: Patent applications of water pollution abatement filed under the PCT (OECD, 2013a)

In addition to the data on access to drinking water and improved sanitation shown in Figures 4.6 and 4.7, an important indicator of the sustainable management of water is water use intensity. Similar to energy intensity, it is defined as the ratio of water input to the useful economic/product output of a system or activity (UNEP, 2012a). The long-term trend of water use intensity can be used to show whether the pattern of water use is decoupled from economic growth (UN, 2013).

Globally, the available data suggest that the freshwater abstraction rate has increased and is in line with the increase in population (Figure 4.9). Global GDP has increased much more rapidly over the last decade – and has therefore been partially decoupled from water abstraction. Within OECD countries, technological change is more evident. Total fresh water abstraction has not changed since 1990, despite increases in population, GDP and public supply. This is due to the use of more advanced irrigation techniques, the decline of water intensive industries, improved efficiency of water use, and increased use of cleaner technologies (OECD, 2012b).

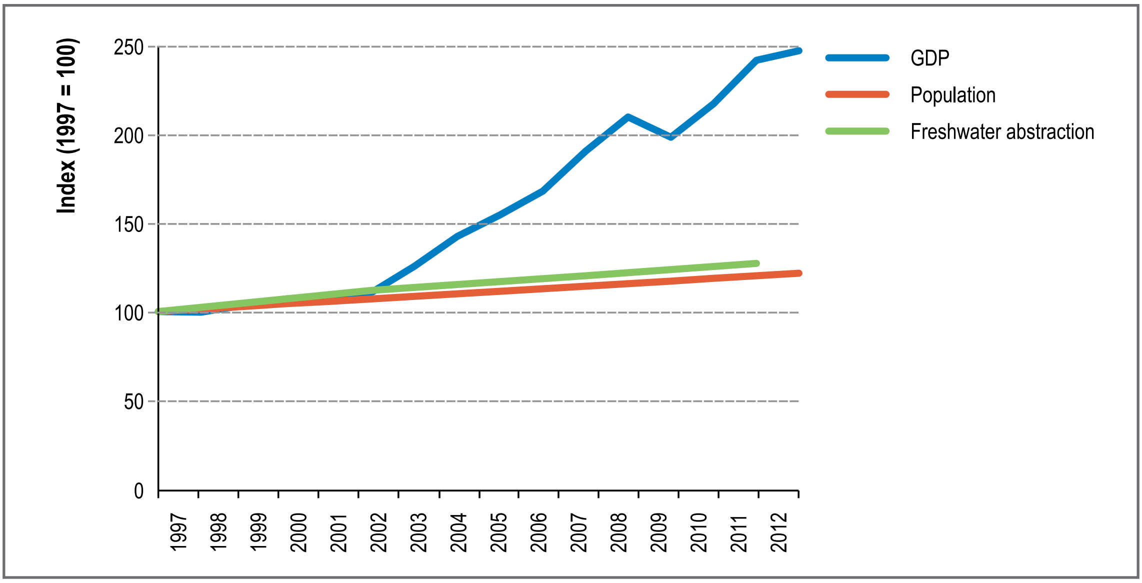


Figure 4.9: Global fresh water abstraction, population and GDP, 1997 – 2012 (World Bank, 2013)

4.2.3 Global Trends in Green Technologies in Waste

Green technology development in the waste sector focuses on three areas: reduction, reuse and recycling. UNEP described the long-term vision for the waste sector as "to establish a circular global economy in which the use of materials and generation of waste are minimised, any unavoidable waste recycled or remanufactured, and any remaining waste treated in a way that cause the least damage to the environment and human health or even creating additional value by recovering energy from waste." The first priority is to reduce waste to a minimum. If waste could not be avoided, reusing materials and energy from waste and recycling waste would be the second priority (UNEP, 2011).

The fifth Global Environment Outlook indicated that underlying global data on waste generation, treatment and recycling are lacking, especially in most developing regions (UNEP, 2012b). This lack of data also extends to indicators of R&D funding and innovation. Figure 4.10 shows trends in applications for patents in waste management. Whilst the number of patent applications has generally risen over time (apart from a significant recent fall), it is difficult to draw any conclusions from these data about trends in the development and deployment of technologies for reuse, energy recovery and recycling.

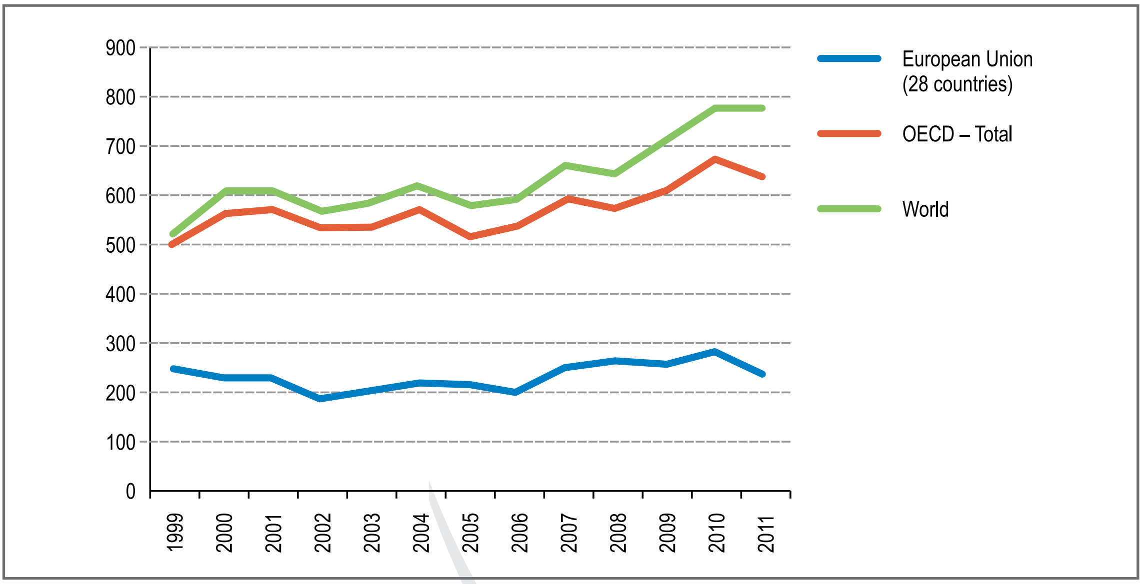


Figure 4.10: Patent application of waste management filed under the PCT (OECD, 2013a)

Government spending on waste management is different across countries. Recently there has been more private involvement in this sector even though investment in this sector has traditionally been financed by local government in many countries (UNEP, 2011). One major international source of funding for greening the waste sector is the World Bank. As shown in Figure 4.11, 199 waste-related projects were funded by the World Bank in 2009.

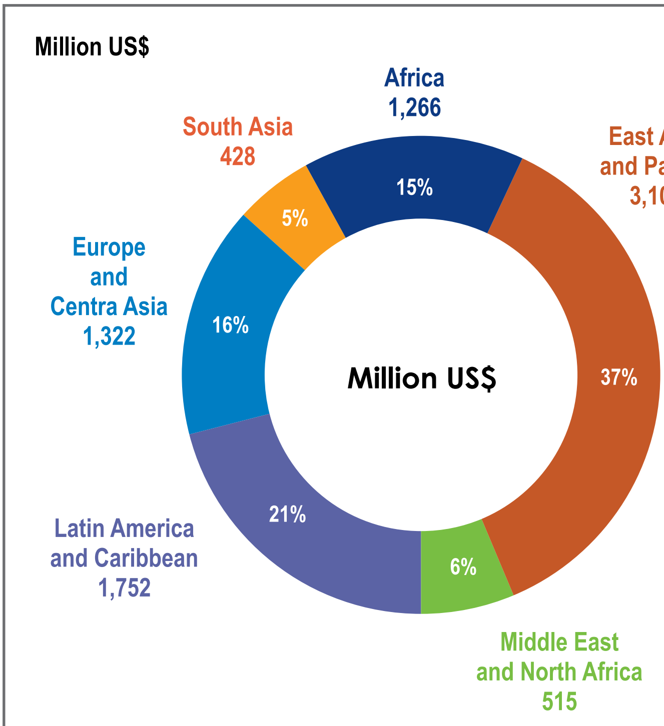


Figure 4.11: The World Bank's investments in municipal solid waste management (UNEP, 2011)

Generally speaking, waste generation is driven by both economic growth and population growth. However in OECD countries, relative decoupling has taken place. Figure 4.12 shows that the quantity of municipal waste generation in the OECD has risen since 1980, but waste generated per capita has increased at a lower rate than private consumption – and has recently started to level off. This is due to the efforts of many OECD countries to encourage waste minimisation, recycling and prevention and to manage materials in a sustainable manner (OECD, 2013b).

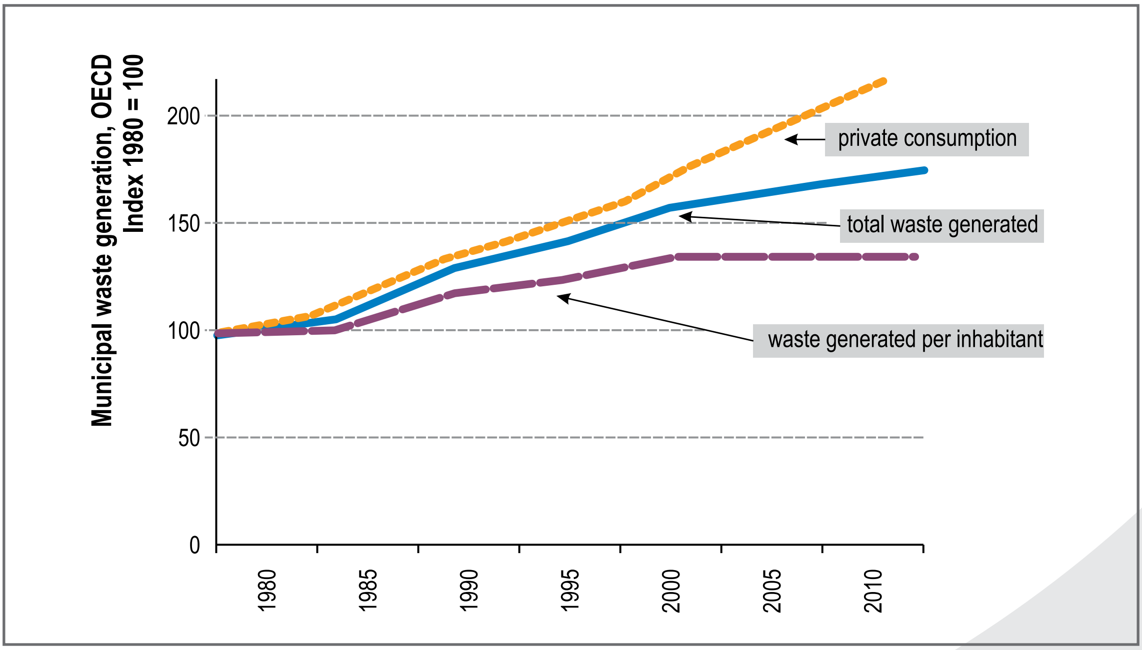


Figure 4.12: Relationship between private consumption and waste in the OECD (OECD, 2008)

In non-OECD countries, waste generation per capita and overall national waste production is also increasing because of the population and economic growth. However, it is estimated that the average annual per capita waste generation in developing countries is at 10% – 20% of the level seen in developed nations (UNEP, 2010b). Due to the increased volume of waste generation, the costs of waste management are also rising. It is expected that by 2025, the costs will reach US$375 billion, compared to the 2010 levels of US $205 billion (Hoornweg, 2012).

4.3 Learning from International Experience

An important question for emerging economies such as South Africa is the extent to which they can catch up with, or perhaps 'leapfrog' the development pathways of OECD countries. If this can be achieved, it may be possible to accelerate the transition to more sustainable provision of energy, water and other services. Related to this, is whether South Africa and other emerging economies can learn from the policy approaches that have already been implemented by countries that are seen as 'leaders' in green technologies.

There is a significant literature that addresses these questions, and focuses on the scope for the transfer of technologies and/or policy frameworks to developing countries – and on the prospects for technological leapfrogging (e.g. Sauter and Watson, 2008). Most of this literature deals with the question of how latecomer countries can catch up with industrialised countries and their level of industrial development. Whilst some of this literature is concerned with environmental and energy technologies (Goldemberg, 1998; Perkins, 2003; Unruh and Carrillo-Hermosilla, 2006), much of it takes a wider perspective and focuses on the broader role of innovation in industrial growth (Soete, 1985; Steinmueller, 2001).

In his groundbreaking paper on technological leapfrogging, Soete (1985: 416) defines technological leapfrogging as: "the opportunities offered by the international diffusion of technology to jump particular technological paradigms and import the more if not most, sophisticated technologies that will neither displace the capital invested nor the skilled labour of the previous technological paradigm, constitute one of the most crucial advantages of newly industrialising countries in their bid for rapid industrialisation".

The literature builds upon the historical evidence of the importance of foreign technology in driving economic growth in Europe and the USA in the second half of the 19th century and Japan in the 20th century. Latecomers to the diffusion of new technologies can expect two advantages: they avoid adopting technologies at an early phase of diffusion that might still be subject to major improvements; and they adopt these technologies when experience has brought their costs down. The fact that no or low levels of capital and skills were accumulated in previous generations of technology can also constitute a major opportunity for latecomers. Latecomers could therefore leapfrog 'vintages' of technology, avoid heavy investments in older technologies, invest directly in affordable up-to-date technologies and finally, catch up with advanced industrialised countries through further innovation (Perez and Soete, 1988).

There are a number of examples in the literature of catching up and/or leapfrogging by emerging economies. These include the case of steel and automobiles in South Korea (D'Costa, 1994; Lee and Lim, 2001) and wind power in India and China (Lewis, 2007; Lewis, 2012). Whilst these examples involve the development, manufacturing and deployment of the technologies concerned within those emerging economies, this does not necessarily need to be the case.

The diffusion of mobile phone technology in developing countries is a good example where the focus has been mainly on investment in infrastructure and consumer adoption. A key factor behind rapid diffusion in this case is that mobile phone technology had been developed and successfully commercialised many years before developing countries adopted it. It had thus been proven as a mature mass-market product at relatively low prices, which strongly enabled the transfer to developing countries (Rouvinen, 2006). However, this case does not necessarily provide a good guide to the potential for leapfrogging in other sectors such as cleaner energy (Unruh and Carrillo-Hermosilla, 2006). For example, many low-carbon energy technologies are still at an early stage of diffusion in major industrialised countries. This means that in some cases, their costs are still high. Therefore, adoption and use depends on national and international policy frameworks for their promotion.

Whether the objective is the deployment of new technologies in an emerging economy or the development of new industrial and manufacturing capabilities in those technologies, the adaptation of technology to the local context is often a necessary condition for success. This is a continuous process that also requires social, economic and institutional changes. The focus cannot therefore be restricted to the physical artefact involved, but needs to include other important dimensions such as human capabilities (Sharif, 1989), policy (Perkins, 2003) or organisational structures (Steinmueller, 2001). Of particular importance is a sufficient level of absorptive capacity within an emerging economy – i.e. the ability of firms, research institutions and other actors to adopt, manage and develop new technologies. Absorptive capacity is often built up over a significant period of time and countries tend to build capabilities in fields related to existing strengths. These capabilities include knowledge and skills and operations and maintenance and further innovation – not just the capability to buy and install new technological hardware (Bell, 2012).

However, the empirical evidence shows that leapfrogging and catching up strategies vary widely (e.g. Hobday, 2003). A country's distinctive resources need to be taken into consideration, and trial-and-error learning needs to be accepted as part of leapfrogging strategies. A common feature of successful leapfrogging is a coherent set of public interventions in support of a long-term leapfrogging strategy. Balanced public interventions to support catching up should be both functional (e.g. generic support for education and critical infrastructures) and selective (e.g. support for specific sectors or industries). In addition, they often need to be tailored to fit with existing policy frameworks in a particular country. Policies that have successfully supported technology development and deployment in one country (e.g. feed-in tariffs for renewable electricity deployment) cannot necessarily be transferred to another country without significant adaptation (Dolowitz and Marsh, 2000; Rose, 1993).

There are a number of risks associated with catching up or leapfrogging strategies. The successful cases show that it is important to support emerging industries without disconnecting them entirely from global competition, as well as international learning and knowledge networks. This balance between indigenous innovation and international sourcing of technologies, skills and capabilities is difficult to strike. Furthermore, an early decision to embark into a certain technological area can lead to picking a losing technology. But late entry into an emerging market can result in 'lock out' if firms within other countries develop faster. Besides this, technical risks and financial risks are critical for many developing countries with scarce financial resources. Emerging economies face difficult policy trade-offs between long-term leapfrogging strategies that aim to build up a sufficient level of absorptive capacity and the provision of immediate basic needs.

4.4 Successful National Approaches to Green Technology

In this section we present the national approaches of Germany and South Korea to the development and deployment of green technologies. The key features that enabled this development are discussed in detail in Appendix 3, with a view to drawing lessons for South Africa and other countries that are considering a similar development path. Emphasis is placed on the policy instruments and other drivers that were designed to underpin a strategic focus on green technologies. Finally, the tangible impacts of the strategies of these countries are identified.

Germany and South Korea were selected as the two case studies since they have had prominent strategies for the development and deployment of green technologies as part of broader 'green growth' strategies. Germany is one of the most widely acknowledged examples of an industrialised, developed country that has sought to implement a shift towards green technologies in energy and other sectors – and to develop new industrial capabilities in these technologies. A significant feature of the German case is the effect of the national environmental movement and the rise of the Green Party that led to increasing support for renewable energy. Paradoxically for some observers, this support has been coupled with a policy of phasing out the country's active nuclear plants by 2022 (Schreurs, 2012).

In contrast, South Korea has gone through an accelerated industrialisation process since the 1960s, which led to a substantial increase in energy demand and GHG emissions (Zelenovskaya, 2012). This industrialisation process included strategies for rapid catching up with (and in some cases leapfrogging of) more advanced industrialised economies in sectors such as steel and automobiles. Following the 2008 global financial crisis, South Korea was one of the first countries that identified green growth and green technology development as a model to guarantee long-term economic growth in conjunction with achieving improved quality of life.

Whilst the energy sector has been central to green growth strategies in both countries, there are some differences in the way green technologies are conceptualised. The differences are particularly apparent in the field of nuclear power. In South Korea, the development and deployment of nuclear power is part of the national green growth agenda and is prioritised in the country's R&D strategy (UNEP, 2010a). On the other hand, in Germany, the planned nuclear phase-out combined with challenging national emissions reduction targets has shifted the focus to renewable energy (Schreurs, 2012). This is linked to a broader strategy known as the *Energiewende* which aims to transform the energy system.

Despite these differences, a common feature between the two countries is that green growth is seen as a way to develop their economy and enable a transition to a new economic model. In addition to supporting green technology diffusion in their domestic markets, a focus on exports and achieving world leader status is considered key to long-term economic growth.

4.5 Conclusions

This chapter has provided some international context for the analysis of green technologies in South Africa. It has shown that there is an increasing global emphasis on technologies to reduce the environmental impacts in the energy, water and waste sectors. Significant public and private funding of these technologies have been coupled with a general increase in patent applications and – in many cases – of technology deployment. However, many indicators of global environmental outcomes are still going in the wrong direction. Global carbon emissions are rising, as are levels of water abstraction and waste generation. The development and deployment of green technologies have not yet successfully addressed many of the world's most pressing environmental challenges.

The chapter has also provided some analysis of technological and industrial strategies to accelerate the development and deployment of green technologies. It has summarised insights from the literature on 'catching up' and leapfrogging by emerging economies such as China, India and South Korea. On one hand, these countries have the opportunity to skip some of the dirtier development pathways that were taken by OECD countries. On the other, significant technological capabilities and the implementation of comprehensive policy frameworks are likely to be required if emerging economies are to take up these opportunities.

Whilst the conditions for 'green growth' (or broader 'green development') will vary significantly from country to country, the chapter has also shown that successful countries are likely to have placed an emphasis on both technological capabilities and policy reforms. The cases of Germany and South Korea illustrate the important role played by a number of factors, including long-term strategies, high levels of political support and consensus, and the successful implementation of detailed policies for industrial development and technology deployment. In both cases, these strategies have also been export-oriented – and have been driven by the desire to create jobs and industrial development, as well as to achieve environmental improvements.

German policies, which have been in place for a long time, have led to many positive outcomes. The South Korean Green Growth Strategy is more recent, and it is too early to tell what impact it will have on that country's economic and environmental outcomes. In both cases, however, the implementation of strategies for 'green growth' has not been entirely straightforward. This illustrates the political nature of strategies to improve the development and use of green technologies significantly, and the likelihood that they will create both winners and losers as economies seek to restructure.

Chapter 5

5 STATE OF GREEN TECHNOLOGIES IN SOUTH AFRICA

5.1 Introduction

The purpose of this chapter is to provide an overview of the state of green technologies in energy, water, waste and sanitation in South Africa. Thereafter, attention turns to green technologies in sectors such as industry, mining, agriculture, ICT, health, transport and buildings. The chapter concludes with a discussion on emerging green technologies.

5.2 Green Technologies in Energy

5.2.1 Introduction

The transformation of the energy sector is central to decoupling economic growth from negative ecological impacts and excessive resource use and shifting to a low-carbon growth path. Green technologies in the energy sector therefore have a critical role to play (Brent *et al*., 2009; 2012).

Given that the South African economy is so heavily dependent on coal, driven largely by low cost and availability, the transformation of the energy sector will take time. Conventional fossil fuel-based energy sources will continue to be a significant source of energy supply for the foreseeable future. To transform the South African energy sector, green technologies, including energy efficient technologies, renewable energy technologies, as well as technologies aimed at producing clean coal should be promoted. These broad categories will form the basis of the assessment of green technologies in the energy sector in this chapter.

5.2.2 Energy Efficiency

5.2.2.1 Policy Framework

The former DME issued a White Paper on Energy in 1998, which promoted energy efficiency (EE) and energy conservation within the framework of integrated resource planning. The National Electricity Regulator (NERSA) issued the Regulatory Policy on Energy Efficiency and Demand-side Management (EEDSM) for the electricity industry in July 2004, which provided the mechanisms for, *inter alia*, access to EEDSM funding and EEDSM awareness raising.

The NEES was published in March 2005 (revised in 2008 and 2012), emphasising the urgent need to solve the energy security problem through EEDSM. A national target of 12% EE improvement by 2015 was set. In May 2010, the DoE published a policy framework document to support EEDSM for the electricity sector, which empowers NERSA to regulate and set the funding level for EEDSM.

Financing of the implementation of EE is obtained mainly through electricity tariffs (De la Rue du Can *et al*., 2013). While the main EE programme is the EEDSM Programme led by Eskom, tax allowances are introduced for EE in Sections 12I and 12L of the Income Tax Act of 1962 as incentives for energy conservation.

In the building sector, the energy efficiency in building standard (SANS 204) that was drawn up in 2009 as a voluntary energy standard was made binding and came into effect in November 2011, targeting newly designed buildings. With regard to the EE of electric appliances, the DoE confirmed the importance of introducing an energy labelling programme in 2009, in its review of the NEES. In the meanwhile, according to the IPAP 2, the South African Bureau of Standards (SABS) is required to develop a national standard for EE and the National Regulator for Compulsory Specification (NRCS) is to formulate a compulsory standard for home appliances. In addition, the government is planning for a carbon tax of approximately R120 per ton of CO_2 in the 2015 budget. The National Treasury released the Carbon Tax Paper for public comment in May 2013 (National Treasury, 2013).

In terms of governance, major reorganisation has led to new legislation and entities to govern and implement EE in SA. In 2009, the DME was split into two separate departments: the Department of Mineral Resources (DMR) and the DoE. The 2008 National Energy Act gives authority to the DoE to conduct the EE policy in South Africa. The dti is also an important actor in the implementation of EE policy, especially standards and labelling, for two main reasons. First, the SABS and the NRCS fall under its authority, and second, the dti's main goals are to enhance the competitiveness of South African industry and to advance international trade. The SABS has signed a memorandum of understanding with the DoE and, as such, has formed a working relationship with them which can be used for setting standards and labelling(UNDP, 2011). The 2008 Energy Act established the South African National Energy Development Institute (SANEDI) to conduct public-interest energy research. SANEDI reports to the DoE and is a combination of the National Energy Efficiency Agency and the former South African National Energy Research Institute (Pty) Ltd which have kept their structure at this point.

5.2.2.2 Supporting Programmes for Energy Efficiency Improvements

The government of South Africa has made large investments in EE projects through many initiatives, the main programme being the EEDSM programme. Other supporting programmes for EE improvement include:

- Public Sector Support: The National Treasury has approved R600 million for the implementation of EE measures in the municipal infrastructure.
- Manufacturing Upgrade Support: The dti has budgeted R5.75 billion to support manufacturing enterprises to upgrade their plant, create jobs, increase their competitiveness and support the value-add process, as well as help companies invest in green technologies.

- Green Energy Efficiency Fund: A joint project between the IDC and the German Development Bank, whereby soft loans (prime rate 2%) of up to R20 million are made available to companies qualifying for EE investments.
- Residential Mass Roll-out: Eskom is currently launching the Residential Mass Roll-out Programme to stimulate bulk replacement of inefficient lighting, implementation of energy-saving technologies and load control devices in the residential sector.
- Solar Water Heating (SWH) and Heat Pumps: Eskom has had a financial incentive programme that aims at promoting the uptake of 1 million SWH units by 2015. However, to date, the programme has fallen short of targets. In November 2010, Eskom began a programme that offers rebates on heat pumps for retrofit or replacement of electric geysers. Unlike the SWH rebates, heat pump rebates are offered up front to buyers; suppliers take on the responsibility of claiming the rebates. The plan is to distribute 65 500 units over the course of the programme.
- Tax Incentives: The National Treasury has announced Section 12L of the Income Tax Act. Both industries and individuals can apply for an energy efficiency allowance from taxable income on the basis of energy efficiency savings. The 12L initiative has become operational very recently and it is not yet possible to determine how successful it will be in improving EE in the industrial and commercial sector.

5.2.2.3 Business Model of EEDSM

Eskom is the main administrator and implementer of NERSA-funded demand-management programmes and has set up an entire division, Integrated Demand Management (IDM), dedicated to EEDSM implementation. Eskom will continue in this role for the interim but it is uncertain whether this will be the case in the future. Besides the Eskom model, municipalities have recently applied directly to the government to receive funds in order to carry out the programme themselves for low-pressure SWHs. In addition, the 12L tax incentive projects will be administered by SANEDI.

5.2.2.4 Measurement and Verification

To monitor the results of the energy conservation measures undertaken, measurement and verification of the resultant savings are of crucial importance for achieving the goal of the EEDSM programmes. According to Eskom, a total of 3 072 MW has been saved since the implementation of their IDM programmes, equivalent to the output of approximately five power stations in the past four years (Eskom, 2012). In terms of the first mass roll-out programme, a total of 2 137 MW has been saved by replacing over 53 million incandescent bulbs with efficient compact fluorescent lamp bulbs. Savings from this programme have contributed to 70% of all savings claimed by the Eskom IDM unit. Several new, more flexible funding mechanisms were introduced in the past 18 months which target mainly the commercial and small industrial sectors. Savings from these initiatives are only now being realised (De la Rue du Can *et al.*, 2013).

5.2.3 Renewable Energy Resources and Implementation

The priority areas for South Africa from a renewable energy perspective, given the policy direction, are those of solar, wind and bioenergy resources. Hydropower potential is limited due to the small number of rivers suitable for generating hydroelectricity and current and projected water limitations in the country (ERC, 2007).

5.2.3.1 Solar Energy

It is estimated that South Africa has about 280 TW of solar energy (CRSES, 2013). The country has amongst the best solar energy resources in the world – abundant sunshine, together with low precipitation and vast tracts of unused flatland. The greatest potential is in the western and north-western parts of the country. However, to date, relatively little has been exploited.

Concentrated Solar Power

Concentrated solar power (CSP) is a simple technology in which solar collectors are used to concentrate solar radiation to achieve high temperatures in a heat transfer fluid (Pitz-Paal, 2013). Currently, CSP is expensive compared with fossil fuel-based plants and will need a variety of incentives to make it cost-effective. However, South Africa could position itself as a leading global player in CSP in the future. To date, two large 100 MW CSP projects have been commissioned (Rycroft, 2013).

Another opportunity is that the materials used to construct CSP plants are (mostly) readily available and many of the components can be manufactured locally. The South African Renewables Initiative (SARi) has estimated that more than 60% of CSP systems could be manufactured locally with little government support. The establishment of local value chains is hoped to drive the CSP industry towards greater commercialisation and eventually drive the price of electricity from CSP systems low enough to make them competitive with conventional generation sources (Edkins *et al*., 2010).

Photovoltaic Systems

There is potential for South Africa to position itself In terms of technology development to support photovoltaic (PV) applications. The current roadmap (RECORD, 2013) highlights that South Africa should primarily consider crystalline silicon (wafer, cell), not only to create a knowledge base for growing the market in the country and elsewhere in Africa, but also to be able to compete in that market – in terms of establishing manufacturers across the PV value chain. R&D activities, over the next five years, to support these focus areas are given in Appendix 4.

Thermal Heating and Cooling Applications

Although policy has not directly supported solar resource applications in the agricultural and industrial sectors, these sectors offer potential in for example, space heating for factories, steam generation for production processes, drying applications, and desalination (Holm, 2009).

Advanced applications, such as solar cooling and air conditioning, industrial applications and desalination/water treatment, are in the early stages of development, with only a few hundred first-generation systems in operation. For the water-stressed regions of the world, much emphasis is placed on driving down the cost of water treatment and desalination, with solar thermal systems. Also, in contrast to many other renewable energy technologies, the majority of firms in the solar thermal heating (and cooling) segment are not listed companies, but large firms from the broader heating and thermal sector or independent actors. They remain highly fragmented, with only one in four companies producing more than 35 MWth (50 000 m^2) per year, and the largest group manufacturing fewer than 7 MWth (10 000 m^2). Thus, South Africa may be able to capitalise on applied R&D to develop products for a growing market that will maximise entrepreneurial opportunities for the country.

CSP Hybridisation

Solar steam augmentation can be used to increase a conventional power station's electricity production or to reduce the amount of fossil fuel required. Either way leads to a reduction in the carbon footprint of the cumulative production of electricity.

As the infrastructure of the conventional power station is already in place, capital costs of solar steam augmentation are significantly reduced. Together with the accompanying reduced risk, steam augmentation plants are likely to reach economic feasibility earlier than stand-alone CSP systems (Turchi *et al.*, 2011).

5.2.3.2 Wind Energy

The wind energy resource of South Africa is estimated by the South African Wind Energy Association to exceed 30 GW. Potential is greatest along the southern and north-east coastline (and associated inland regions). Wind farms offer the largest immediate potential for input into the national electricity grid, and for significantly alleviating South Africa's power supply shortage. The technology is mature, and is mainstreamed globally (Trollip and Marquard, 2010).

5.2.3.3 Biofuels

Biofuels are liquid or gaseous fuels derived from organic material or biomass. They are particularly important for the transport sector as a replacement for fossil fuel-based fuels. Biofuels include bioethanol, biomethanol, biodiesel and biohydrogen. Generally, biofuels are categorised into conventional or first-generation biofuels and advanced or second-generation biofuels (WBA, 2013). The former are based on feedstocks, such as corn, cereals, canola and soybean, whereas the latter are based on cellulosic feedstock such as straw, bagasse, rice husks, organic waste and algae. Second-generation biofuels are mainly in the pre-commercialisation or early commercialisation phases.

The national biofuels policy (DME, 2007) set a target of 2% of fuel supply from biofuels by 2013. Maize is excluded as a feedstock and biodiesel feedstock is limited to soybeans, canola or sunflower oils, and the production of ethanol is restricted to sugar cane or sugar beet. There is provision for fuel tax exemptions of 50% for biodiesel and 100% for ethanol in the policy. To alleviate concerns about competition with food production, there is a focus on new and additional agricultural land.

At present, biomass is used for co-generation of heat and electricity in the paper and sugar industries, and biogas is generated, for example, from waste biomass in breweries. The use of biomass as an energy source is also supported by the Working for Energy programme.

The position paper on the South African Biofuels Regulatory Framework (DoE, 2014) acknowledged that biofuels projects are on their own not financially attractive at the prevailing feedstock and crude oil/liquid fuels prices. The position paper proposed that a better regulatory environment be created that is more conducive for the production of biofuels. Actions include:

- Blending of a minimum of 5% biodiesel (v/v) and 2% bioethanol (v/v) with fossil fuels will be mandatory as from 1 October 2015.
- Eight manufacturing licenses (four bioethanol and four biodiesel licences) have thus far been granted by the DoE.
- The DoE is working on an appropriate Biofuels Pricing Framework in conjunction with the National Treasury.
- A levy earmarked for the subsidisation of manufacturers of biofuels will be part of the General Fuel Levy applicable to all petrol and diesel consumed nationally.

Research projects are underway at a number of South African universities on the production of biofuels, including biodiesel from algae (University of the Western Cape, Durban University of Technology) and bioethanol from biomass (Stellenbosch, Rhodes, Free State Universities). Significant progress has been made in the conversion of cellulosic feedstocks, such as agricultural residues, to biofuels at Stellenbosch University.

When advanced second-generation biofuel technologies come to fruition and 50% of the residual lignocellulosic biomass (almost 50 Mt on an annual basis) is used, biofuels could play a significant role in South Africa's transport fuel future (Lynd *et al.*, 2003).

5.2.3.4 Concluding Remarks

A number of outstanding issues are delaying initiation of the renewable energy industry in South Africa due to the required technical and policy investigations, however, the country is set to become a global leader in renewable energy roll-out. Although the local renewable energy industry is currently in its infancy stage, it possesses long-term potential for growth and job creation.

Considerable experience in renewable energy research exists in South Africa. Harnessing its science and technology potential, relative economic prosperity and strategic geographical position at the southern tip of Africa, South Africa can change its role from being the main emitter of CO_2 in Africa, to the technology provider to set Africa on a future path of sustainable development.

5.2.4 Clean Coal Technologies

5.2.4.1 Introduction

Currently coal supplies 92% of the primary energy and 40% of the country's liquid fuel. Furthermore, coal provides 98% of the carbon-based requirements in the iron and steel industry in the form of reductants (coke, char and anthracite) used to reduce metal oxides to metals. Coal also supplies heat and power to approximately 6 000 smaller-scale industrial users for process heat and power, including the pulp and paper, sugar, brick and tile, cement and lime, food and chemical industries.

In order to maintain the country's current basic source of energy whilst alternatives (renewable energy and nuclear power) are in the ascendency, urgent steps are required to reduce GHG emissions, specifically CO_2 from coal consumption. The introduction of clean coal technologies includes, *inter alia*, the upgrading or beneficiation of South Africa's poor-grade coals to produce a product with significantly improved combustion efficiencies and thereby significant emissions reduction in power generation, process heat production, metallurgical processes and when using coal as a source for valuable carbon-based solid, liquid and gaseous chemicals. Such processes must also be designed to provide greater operational efficiencies and in a manner that requires little or no water, given the paucity of water in the country.

5.2.4.2 Clean Coal Technology

Clean coal technology is applicable during both coal extraction and use. Whilst the term generally refers to the use of coal for power generation, it also applies to all other aspects of coal utilisation, e.g. gasification, coal-to-liquids and chemicals, metallurgical iron, steel and ferroalloy manufacture, and cement, brick, pulp and paper production amongst others.

Coals must be used in the most efficient manner in order to maximise the output of, for example, steam and power, with the minimum of GHG emissions. In essence, this implies that the boiler or gasifier must obtain the most suitable coal qualities to meet plant design specifications or the boiler or gasifier must be designed to meet the grades available. The different GHGs emitted during use are then handled accordingly. Low NOx burners and post-combustion ammonia-based processes for NOx reduction are installed to prevent NOx emissions; SOx is reduced either in the pre-utilisation phase by means of beneficiation (whereby sulphur in the form of the mineral pyrite (FeS) is extracted from coal) or in post-utilisation where it is captured in gaseous form during flue gas desulphurisation. CO_2 is captured pre-, during and post-utilisation using various methods and is then transported to various suitable geological sites for injection, storage and monitoring.

5.2.4.3 Challenges in using Coal in a Low Carbon Economy

Achieving the proposed reduction in GHG emissions while coal remains a significant element in the energy mix is hampered by a number of factors.

The first challenge facing the continued use of coal in South Africa is that the coal now being mined is of a lower quality than was the case in the past, primarily because the best qualities have largely been mined out for both local and export purposes over the past 60 years. This situation poses major challenges throughout the coal value chain as many coal plants brought into this country over the years – both for production and utilisation – were designed for high grades of coal. Such low-combustion efficiencies require more tons of coal being burnt to produce a given energy output, resulting in turn, in the production of high emissions of GHGs for every megawatt or ton of steam produced.

To reduce CO_2 emissions further, a major improvement in efficiency is required, which can only be achieved by the introduction of new clean coal technologies. With the introduction of super and advanced super-critical pulverised power stations and integrated gasification and combined cycle (IGCC), efficiencies increase and CO_2 emissions drop further, but major emission reduction is considered possible only through CCS.

Limited water capacity in the country further exacerbates the situation because almost all beneficiation, utilisation and environmental processes require water to operate in one form or another. To minimise water use, Eskom has installed the first dry-cooling towers at Matimba Power Station, Limpopo province, whilst dry de-shaling technologies are now being introduced in some beneficiation processes. Such processes, however, come at ever-increasing costs.

5.2.4.4 Upgrading or Beneficiation of Coal prior to Use

The upgrading or beneficiation of South Africa's poor-grade coals is of vital importance as it can separate out good grades of coal from poor, thereby providing a range of products for use in industry.

Considerable work has also been conducted on increasing the operational efficiency of various conventional washing plants, improvements in the designs of existing plant equipment and the introduction of new processes. Furthermore, an integration of two or more beneficiation process plants in sequence has been found to increase the levels of separation between good coal and contaminating materials. A number of such multi-process plants are currently on trial.

5.2.4.5 Carbon Mitigation Technologies – Carbon Capture and Storage

South Africa has a relatively high carbon footprint per capita. As a result, CCS offers an important means to limit CO_2 emissions from large-scale energy-intensive sources. Research has been undertaken into the potential for CO_2 storage and in 2010 a national geological survey of potential storage sites in the country was undertaken, both on land and off-shore. The results indicated that, without further research, less than 2% of potential storage is available on-shore, with the bulk some distance off-shore in gas fields along the southern and western coastlines of the country.

5.2.4.6 Coal Combustion and Power Generation

Establishing higher efficiency coal-fired power plants is seen as an important and near-term step in reducing carbon emissions.

Modern systems of replacements or upgrading for large-scale power plants include clean coal technologies, such as changing sub-critical power plants that operate at modest temperatures to super-critical and ultra super-critical plants which operate at much higher temperatures.

Attempts to increase efficiency in South Africa's other sub-critical large-scale coal-fired power stations are on-going and difficult. The qualities of coal being fed to the stations do not match the original specifications provided by the boiler manufacturers. In order to improve the situation, de-shaling (removal of rock) of the coal-feed prior to it being fed into the mills, and installation of on-line analyses to check the qualities of coal prior to combustion, are undertaken.

Improved efficiencies in industrial boilers are a further area of concern and in need of urgent attention. Approximately 6 000 industrial boilers provide heat and power generation for a wide range of industries in South Africa. Many of these boilers were imported from the United Kingdom, Europe or the USA during the period 1950 to 1970 and were installed with coal-quality specifications equal to those used in their countries of origin.

In the short term, boiler manufacturers are now hard pressed to design and produce equipment that will provide adaptations to existing plants to ensure more efficient operation and to reduce particulates and GHGs emitted from such boilers.

In the medium to longer term, the methods underway for reducing emissions, increasing efficiencies and providing a source of energy and related products for South Africa are:

- Underground coal gasification: This is designed to reduce CO_2 emissions, to utilise deep otherwise-sterilised and lower-grade coal seams, to provide gas for power generation and gas-to-liquids, and is overall more cost-effective and efficient than conventional coal-fired power stations.
- Co-firing with biomass: Co-firing coal with biomass to reduce CO_2 emissions is currently being practised in South Africa by some paper, pulp and sugar industries.
- Co-generation: The capture and use of waste heat in power generation, metallurgical plants or other industrial coal-fired process operations is currently being undertaken as a further step in CO_2 abatement in those industries.
- Conversion of coal-fired boilers to gas: The combustion of gas is considerably more efficient than coal and produces considerably lower CO_2 emissions.
- Introduction of new clean coal technology boiler plants such as fluidised-bed combustion.
- CCS and GHG emissions: In anticipation of impending carbon taxes and limits on CO_2 emissions, all new large-scale power plants in South Africa will be required to be CO_2 capture-ready in preparation for full-scale capture in due course.

5.2.4.7 Carbon Capture

Large-scale CO_2 capture systems on coal-fired power plants are still at the pilot stage in a number of research centres round the world. Certain larger demonstration units are now being planned but there are no full-scale operations as yet. South Africa has not as yet entered into any serious levels of R&D in CO_2 capturing, apart from initial oxyfuel combustion investigations currently being undertaken at the Council for Scientific and Industrial Research (CSIR). Being aware of international developments in CO_2 capture is, however, of paramount importance to South Africa as any future large-scale coal-fired power plants will be required to be CC-ready when built.

5.2.4.8 Co-firing with Biomass

There is increasing interest in the use of biomass for reducing CO_2 in power generation. This is based upon the concept that if biomass is grown in a regenerative manner, its combustion will not produce any net CO_2 emissions, i.e. growing plants ingest CO_2 and produce O_2 to the atmosphere, so the CO_2 produced when the biomass is combusted equates to the CO_2 ingested by currently growing plant populations. Co-firing of biomass with coal is particularly attractive to coal-fired power generators as it is considered to be one of the simplest ways to reduce CO_2 emissions from a coal-fired power plant. There are, however, a number of issues associated with co-firing biomass with coal due largely to the difference in fuel composition and physical and combustion characteristics. This includes difficulties in handling and crushing to adequate pulverised sizes and to transporting it via ducts into the boilers due to its low density relative to the heavier pulverised coal particles. Biomass materials also have different chemical compositions and combustion characteristics.

One further area of research in South Africa involves the growth of algae, both as a source of biomass for power generation and as a natural and sustainable CO_2 sink (consumer). Initial results showed that increased CO_2 concentrations in algal ponds can lead to a 12-fold increase in the growth of the algal population. In addition, excess algal mass can be used to produce associated food products, liquid fuels and other high-value industrial products and it has been shown to support fish culture.

5.2.4.9 Concluding Remarks

Considerable opportunity exists to reduce the environmental impact of coal usage in various quarters of the South African industry leading to increased process efficiency and reduced GHG emissions, but these come at a cost. Given the high dependency on coal for the country's energy, liquid fuels and metal products, great care will need to be taken in future to achieve the correct balance between environmental responsibility and socio-economic and industrial development.

5.3 Green Technologies in Water

5.3.1 Introduction

Water provision is the most basic intervention and requirement for poverty alleviation. In addition to the well-documented economic, social and environmental impacts of poor water supply and sanitation (Mara, 2003; Moore *et al.*, 2003; Johnson *et al.*, 2007; Montgomery and Elimelech, 2007), the health and welfare of people, especially of vulnerable groups, such as children, the elderly and poor, are closely related to the availability of adequate, safe and affordable water supplies (Theron and Cloete, 2002; Ashbolt, 2004; Eshelby, 2007).

In South Africa, there are still millions of people who are 'water poor'. According to the latest statistics (StatsSA, 2013a), almost 10% of the population lacks access to piped water. Of the component of the population with access to piped water, only 44.5% had access to piped water in the dwelling. The remainder experienced access either through piped water on-site, at their neighbour's dwelling or communal taps. A small percentage (2.3%) still relies on rivers, streams and dams for drinking water.

Moreover, increasing pollution of groundwater and surface water from a wide variety of industrial, municipal and agricultural sources has seriously tainted water quality in these sources, effectively reducing the supply of fresh water for human use (Kemper, 2004; Foley *et al*., 2005; Coetser *et al.*, 2007). Although the nature of pollution problems may vary, they are typically due to inadequate sanitation, algal blooms fertilised by the phosphorus and nitrogen contained in human and animal wastes, detergents and fertilisers, pesticides, chemicals, heavy metals, salinity caused by widespread and inefficient irrigation, and high sediment loads resulting from upstream soil erosion (Ritter *et al.*, 2002; Fawell and Nieuwenhuijsen, 2003; Mara, 2003; Falconer and Humpage, 2005; Foley *et al.*, 2005).

Given the importance of potable water provision to all people and taking into account concerns regarding the viability of current practices of meeting the increasing demands of all water users (Weber, 2002), there is a clear need for the development of innovative and low-cost green technologies and materials whereby challenges associated with the provision of safe potable water can be addressed.

5.3.2 Applications of Green Technologies in the Water Sector

5.3.2.1 Management of Algal Blooms

Eutrophication of water sources, caused by a high inflow of nutrients such as phosphates and nitrates, often results in toxic algal blooms. The decay of algal matter may lead to oxygen depletion in the water, which in turn can cause secondary problems, such as fish kills from lack of oxygen and the liberation of toxic substances or phosphates that were previously bound to oxidised sediment. The Hartbeespoort Dam is one such dam, which is dominated for most of the year by visible cyanobacterial or algal blooms.

It is accepted that phosphorus control is more achievable than that of nitrogen; a small degree of phosphorus reduction can achieve a much greater degree of growth reduction of cyanobacteria than a reduction of a similar magnitude in the nitrogen level. A green technology, using lanthanum-modified bentonite (Ross *et al.*, 2008) and/or lanthanum-modified zeolite (Ning *et al.*, 2008) has developed as a specially modified phosphorous binding clay and proven effective in euthrophication control. It reduces phosphorus levels, neutralises the pH of the water and acts as a successful algal flocculant.

These specific products do not negate the improvement and optimisation of biological wastewater treatment systems and specifically, systems designed for enhanced nutrient removal.

5.3.2.2 Acid Mine Water Treatment

The production of effluents containing high concentrations of sulphate and heavy metals, and having a low pH, is a worldwide problem primarily associated with the mining industry. Known as acid mine drainage (AMD), these effluents lead to various environmental problems, killing aquatic life, as well as presenting economic problems due to their highly corrosive properties.

AMD may be remediated by neutralising the effluent and removing the sulphate and metals. Various active sulphate removal technologies are available (Hulshoff Pol *et al.*, 2001), however, they are linked to negative effects, such as the production of large amounts of sludge and brine that require disposal at additional cost. Widespread application of these active AMD treatment processes has not yet occurred, probably due to the high costs involved, as well as to the degree of maintenance and supervision required. However, depending on fitness for purpose (irrigation, industrial or potable) and the level of purity required, the cost will vary and in some cases may be cost-effective.

There is an increasing demand for inexpensive, green technologies to remediate AMD. One such potential technology is the so-called passive treatment system, defined as a water treatment system utilising naturally available energy sources such as microbial metabolic energy, photosynthesis, chemical energy, and the use of natural topographical gradients to regulate flow. Sulphate reducing bacteria drive sulphate reduction in passive treatment systems and utilise organic compounds, if a suitable electron donor is available for the reduction of sulphate to sulphide (Dill *et al.*,1994).

The most cost-effective and available organic electron donors are of plant material (wood chips, silage, grass, etc.) or industrial and/or municipal waste (sewage, sludge, etc.) (Howard *et al.*, 1989). Their effectiveness in the passive treatment of AMD depends on their chemical composition, specifically the ratio of components such as lignin, hemicellulose, cellulose, proteins and carbohydrates. Malherbe and Cloete (2002) provide further details on their biodegradability and on other forms of organic electron donors.

One of the limitations of passive treatment systems is the availability of readily available carbon sources to drive sulphate reduction over the design life of the passive treatment system (~20 years). Another technology is the BioSure process that takes care of two waste streams at the same time. Although the carbon availability problem did arise, the Water Research Commission (WRC) is currently funding a project to overcome this hurdle with positive results to date.

5.3.2.3 Potable Water Provision

Microbiologically contaminated water impacts the health of people, especially in rural areas, where there is a lack of treated water and where people drink directly from their respective water sources without any treatment. There is thus an urgent need to implement low-cost, simple, sustainable and effective technologies for the production of satisfactory drinking water in these areas to prevent the spread of water-borne diseases.

Solar water pasteurisation is one such green technology that has shown that it is possible to decontaminate sewage water of faecal indicator bacteria by heating water to temperatures above 60°C (Nevondo and Cloete, 1999). Both these technologies, solar pasteurisation and UV disinfection, are low-cost green technologies that can be used to treat water and contribute to solving the challenge of the provision of clean drinking water for all South Africans, particularly those in rural areas.

5.3.2.4 Nanotechnology Applications in Water Treatment

Nanotechnology has been identified as a technology that could play an important role in resolving or ameliorating many of the problems involving water purification and water quality (Savage and Diallo, 2005; Bottero *et al.*, 2006).

Potential impact areas for nanotechnology are divided into two categories as follows (Masciangioli and Zhang, 2003; Rickerby and Morrison, 2007; Vaseashta *et al.*, 2007):

1. Treatment and remediation – nanotechnology has the potential to contribute to long-term water quality and availability, and the viability of water resources, through the use of advanced filtration materials that enable greater water reuse, recycling, and desalination.
2. Sensing and detection – of particular interest is the development of new and enhanced sensors to detect biological and chemical contaminants at very low concentration levels in the environment, including in water. Moreover, nanotechnology has the potential to facilitate the development of continuous monitoring devices capable of yielding real-time measurements at lower cost and with improved specificity, allowing municipalities to react more quickly to potential crises (Riu *et al.*, 2006; Vaseashta *et al.*, 2007).

5.3.2.5 Rainwater Harvesting

Rooftop rainwater harvesting (RWH) can play a major role in sustainable water provision, contributing to water conservation in urban areas and in providing access to water. RWH involves the small-scale collection, capture and storage of rainwater runoff for different productive purposes, including irrigation, drinking and domestic use. RWH is thus considered one of the alternative water resources that may enable South Africa to meet the goals set by the government, and to ensure people’s well-being. This practice is currently spreading in rural areas throughout the country, especially with the financial assistance provided by government to resource-poor households for the capital cost of rainwater storage tanks and related works.

Advantages of rooftop RWH include direct management by households, provision of water at or near the point-of-use. The chemical quality is generally acceptable for general use (non-human consumption). However the microbiological quality does not meet potable standards and hence further treatment is required before the water can be used for human consumption. There is a risk of spreading water-related diseases and hence education to avoid water contamination is necessary.

5.3.2.6 Information and Communication Technologies in Water Delivery

In order to deliver water to millions of people in a sustainable way in the future, smart water delivery systems using tailor-made software will be used. Information and communication technologies (ICT) can be a useful tool to manage water delivery (Goodall *et al.*, 2011). Increasingly factors such as climate change, energy availability for pumping water, and unpredictable rainfall causing water scarcity are making it more complex to deliver water. The availability of real-time information about the physical environment has become crucial for the management of water (Kanwar *et al.*, 2010). These variables include temperature, soil moisture, dam levels, rainfall, leakages and real-time water consumption, etc. ICT provides a platform to integrate geographical information system data (Fengyun and Xiaochun, 2010) with satellite data, enabling climatologists to model weather forecasting that may lead to innovative solutions to water management better, especially in water scarce areas.

5.3.3 Concluding Remarks

Provision of potable water to all people in South Africa presents a challenge and there are millions of people without access to a potable water supply. This presents an opportunity for the development of innovative, low-cost green technologies aimed at potable water provision. Examples include solar water pasteurisation, UV disinfection and RWH. Nanotechnology also has a role to play in improved water quality. South Africa also faces many water quality challenges linked to urban and industrial activities. Increasingly, green technologies are being used to solve these problems.

5.4 Green Technologies in Waste

5.4.1 Introduction

Waste management is currently undergoing a major global paradigm shift. This shift is driven by issues of climate change, carbon economics and resource scarcity, and requires that waste no longer be viewed as an unwanted by-product requiring disposal to landfill, but rather as a renewable resource, suitable for re-introduction back into local and global economies (Perella, 2013). This paradigm shift from one of a linear to a circular economy creates significant economic and social opportunities. These opportunities provided by the waste sector are integral to the larger discussion underway with regard to greening the economy.

This paradigm shift is having a significant influence on waste technologies, as the waste sector seeks out alternative solutions to traditional disposal of waste to landfill. As noted by Perella (2013:21), as the resource management agenda unfolds, the biggest commercial opportunities will arise from "smarter value extraction techniques. This will require a strong need for technical innovation". Moving waste up the hierarchy away from disposal towards waste prevention, reuse, recycling and recovery will require new technological innovation (Figure 5.1). Globally, government, business and academia are investing in alternative waste technologies which efficiently, and cost-effectively, recover resources from waste. Green technologies within the waste space are therefore seen as technologies which will facilitate such a move up the waste hierarchy and which will maximise resource recovery. The rationale of moving waste up the hierarchy is ultimately one of improved environmental outcome (DEFRA, 2013a). However, alternative waste management solutions should only be adopted if the environmental, social and economic benefits outweigh those of disposal.

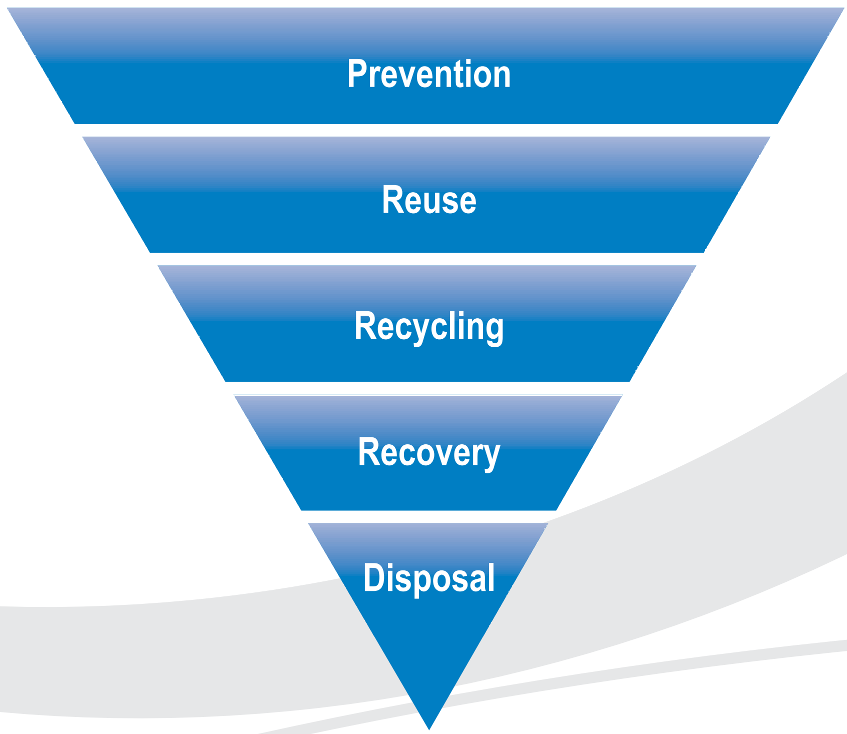


Figure 5.1: Waste hierarchy

The following sections explore these emerging waste technologies and the opportunities they present for South Africa.

5.4.2 Global Trends in Waste Technology

A recent study on the impact of a circular economy on the waste sector, found that the majority of businesses are moving waste up the hierarchy by focusing on increasing recycling rates, better waste prevention, a greater focus on waste reuse, setting zero-waste to landfill targets and energy recovery (Perella, 2013). Waste recycling and recovery, and associated technologies, have become a key focus under the green economy.

Recent Eurostat data for 2010 show this transition away from landfilling towards recycling and recovery within the European Union (EU) (Figure 5.2). While differences in waste management technologies exist between EU member states, the EU, as with most developed countries, is showing a move away from waste disposal to landfill, to resource recovery (other than energy) (which includes recycling) and energy recovery (Eurostat, 2013). Countries such as the Czech Republic, Poland, Italy, Germany, Denmark and Belgium have managed to reduce the quantity of waste disposed to landfill, to less than 25% (Figure 5.2).

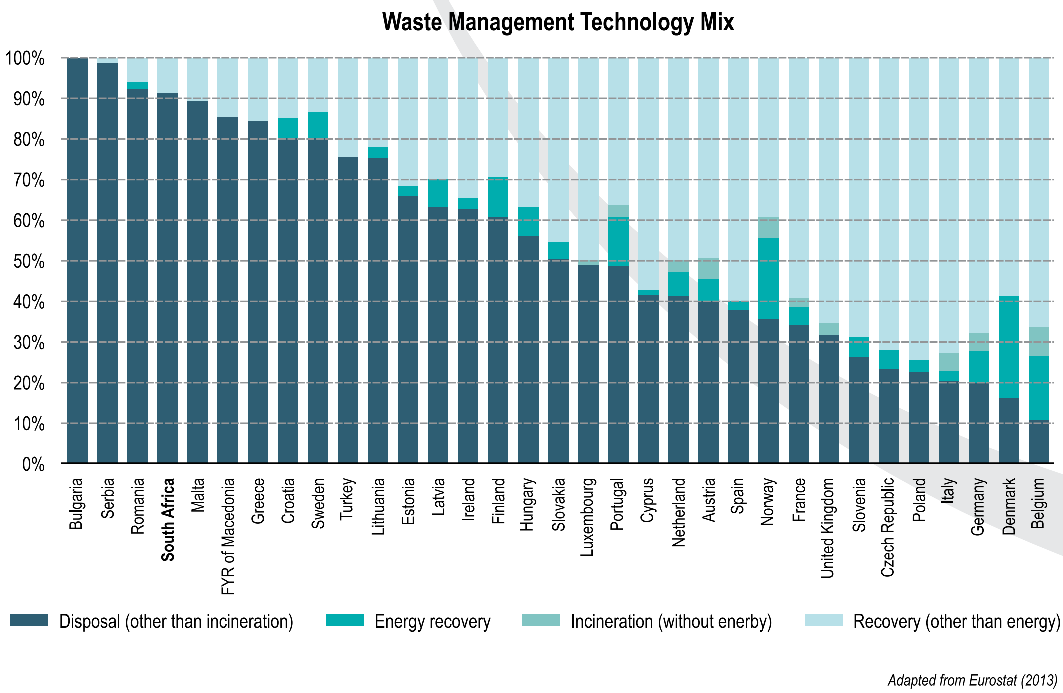


Figure 5.2: Mix in waste management technologies within the EU member states (2010) and South Africa (2011) (EuroStat, 2013; DEAT, 2012)

The USA has shown slight year-on-year improvements in the percentage of municipal solid waste recovered over the past five years (2006 – 2011), with the most recent figures for 2011 that of 46.4% recovery (including energy recovery) and 53.6% disposal of waste (US EPA, 2013).

Asia is also driving this trend towards increased recycling and recovery. The 12th five-year plan for national economic and social development of the People's Republic of China (2011 – 2015) (CBI, 2011) has identified two specific areas of socio-economic development relating to waste:

- Cultivating and developing strategic emerging industries, one of which focuses on an energy conservation and environmental protection industry, including recycling.
- Vigorously developing a circular economy, including implementing circular production methods; enhancing the circular use of resources and recycling systems; popularising the green consumption model; and strengthening policy and technical support.

Major areas of waste recycling technology identified by China in the 12th five-year plan for waste recycling technology (China Briefing, 2012) are very similar to those emerging from Europe, and include:

- Waste recycling and recovery of metals (i.e. scrap metal, waste electronics, used electro-mechanical products) and plastic (recycled polymer).
- Recycling of large industrial waste streams, e.g. fly ash, gypsum, mining waste, etc.
- Energy recovery from waste, e.g. domestic waste, industrial and sewage sludge.

Waste recycling and recovery technologies cover a wide range of waste streams and technology types, too extensive to cover in any detail in this report. These technologies include mechanical, thermal, chemical and biological processes (VTT, 2012). The ultimate aim of these technologies is to recover viable resources, such as polymer, fibre, ferrous and non-ferrous metals, etc., from within the waste and re-introduce them into the manufacturing economy in order to make new products. While paper can be recycled five to seven times before the fibres become too short to be useful, other materials such as glass and metals can be recycled indefinitely. The number of times that plastic can be recycled varies, depending on the plastic type and the new product into which it is to be used (US EPA 2013b; VTT, 2012).

Given the current limitations, the future of recycling and recovery technologies will need to be on (VTT, 2012):

- increased efficiency in material recovery and recycling;
- design for dismantling and recycling, in response to the increasing complexity of products and related wastes;
- improved feedstock management, including increased access to recyclables (quantity) and to clean recyclables (quality).

Energy-from-waste (EfW) technology is a blanket term for a range of technology types, including both thermal and non-thermal technologies, aimed at creating energy in the form of electricity, heat or transport fuels (DEFRA, 2013a; ISWA, 2013). Current examples of thermal EfW technologies include conventional incineration/ combustion, and advanced[3] thermal treatments such as gasification, pyrolysis, plasma gasification and thermal depolymerisation. Examples of non-thermal EfW technologies include anaerobic digestion, fermentation, mechanical biological treatment and landfill gas recovery (REA, 2011; DEFRA, 2013a; Funk *et al.*, 2013;

[3]Also often referred to as alternative thermal treatment.

ISWA, 2013; McDonald, 2013). Within each of these EfW processes, there are a wide variety of individual technologies.

As the use of EfW technologies grows and becomes part of the standard technology portfolio of a country, there is increasing debate around the trade-off between recycling and energy recovery. From a circular economy and resource recovery philosophy, EfW should be seen as a complementary technology to recycling, with the approach to integrated waste management being one of first waste prevention, followed by maximising waste reuse and recycling and finally recovery, including energy recovery (REA, 2011; DEFRA, 2013b). EfW technologies are therefore typically concerned with recovering energy from residual waste, once all economically viable recyclables have been removed (DEFRA, 2013a). If countries are successful in achieving the top orders of the waste hierarchy, potentially less residual waste will be available for energy recovery. According to DEFRA (2013a:22), "government's aim is to get the most energy out of residual waste, rather than to get the most waste into energy recovery".

The focus of future EfW technologies are therefore largely on (DEFRA, 2013a; Funk *et al.*, 2013):

- higher-efficiency energy recovery, both in terms of resources and cost;
- flexibility to long-term changes in residual waste feedstock so as to support the move up the waste hierarchy, rather than constrain it;
- coping with the heterogeneous nature of municipal solid waste feedstock, which can result in the widely varying chemical composition of the energy products.

5.4.3 Local Trends in Waste Technology

5.4.3.1 *Status Quo* in South Africa

South Africa is still largely at the periphery of this global transition towards a circular economy. The promulgation of the National Environmental Management: Waste Act (*Act 59 of 2008*) (NEM:WA) (RSA, 2009b), underpinned by the principle of the waste hierarchy, is prompting change within the South African waste sector. However, as at 2011, 90.1% of all general and hazardous waste generated in the country was still disposed of to landfill sites, often uncontrolled open dumpsites. Only 9.8% of generated waste was recycled and 0.1% treated (DEAT, 2012). The current portfolio of waste technology solutions for South Africa is therefore still heavily reliant on landfilling (Figure 5.3).

As with most developing countries, where recycling is occurring in South Africa, it is largely driven by the informal waste sector, currently estimated to provide a living for some 60 000 – 90 000 people (World Bank, 2012; DST, 2013). The informal sector in South Africa is thought to collect 80% of glass, 90% of polyethylene terephthalate plastic and the majority of the recovered paper into the recycling economy (BMI, 2013). This has resulted in fairly good (by international standards) recycling rates for packaging material including glass, metal, paper and plastic (BMI, 2013).

The national Waste Sector Survey for 2012 (DST, 2013), also highlighted the heavy reliance on landfilling as a technology option in both the South African private and public waste sectors. The study showed that while the private sector is introducing (to some degree) alternative technology solutions, municipalities still rely very heavily on landfilling as the primary solution for the management of waste (Figure 5.3).

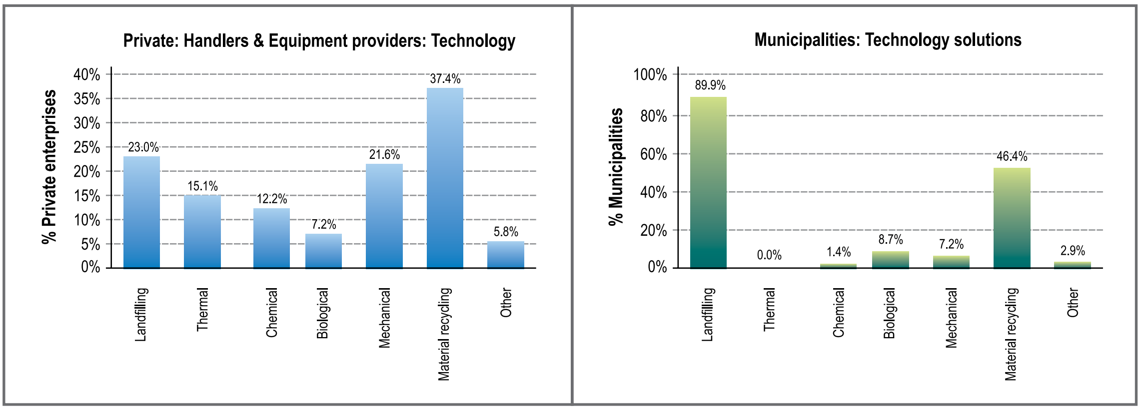


Figure 5.3: Technology solutions in the private and public waste sector in South Africa (DST, 2013)

When one considers that approximately 13% of general waste generated in South Africa is municipal organic waste (DEAT, 2012), collected predominantly by municipalities, and an additional 61% industrial biomass waste, it is surprising that biological treatment (e.g. composting, anaerobic digestion) is not utilised more extensively in South Africa. Large quantities of waste biomass, for example, food waste and agricultural biomass, are being generated by industry, yet thermal and biological technologies remain under-utilised. Industrial biomass presents the largest, single type of general waste generated in South Africa at an estimated 36 mT per annum for 2011.

5.4.3.2 Emerging Technologies

A review of registered waste patents in South Africa, over the period 2007 - 2012 was conducted by the CSIR to assess the potential introduction of new waste technologies into South Africa (future trends). A search of patent title keywords showed a strong leaning towards high and low-temperature EfW technologies ('fuel', 'incineration', 'combustion', 'anaerobic digestion' and 'pyrolysis') and recycling (DST, 2012a), which mirrors international trends in new waste technologies towards recycling and recovery (Figure 5.4).

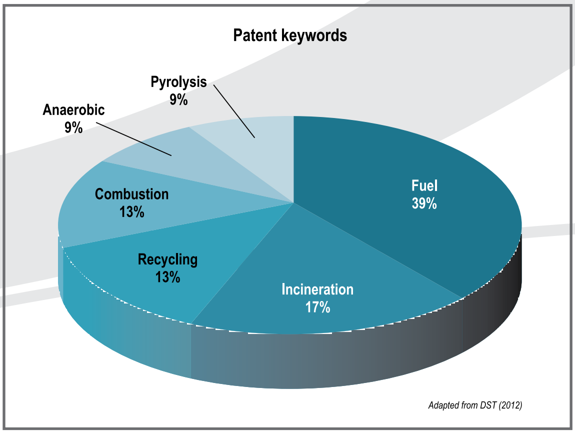


Figure 5.4: Patent keyword search results

However, according to DST (2012a), the majority of these patents (86%) were non-South African owned. This would suggest that international companies see South Africa as an attractive market for the introduction of green technologies, and have begun to protect their intellectual property locally.

5.4.4 Technology Opportunities for South Africa

5.4.4.1 Innovation Activity within the Waste Sector

The Waste Sector Survey for 2012 (DST, 2013), showed that while both the private and public waste sectors are innovating, the innovation activity remains relatively low (Figure 5.5). This is to be expected given that currently, only 10% of waste is diverted to alternative technology solutions. The private waste sector showed a noticeably higher innovation activity than the public sector, which would suggest that waste businesses are beginning to recognise the business opportunities in the move towards a circular economy.

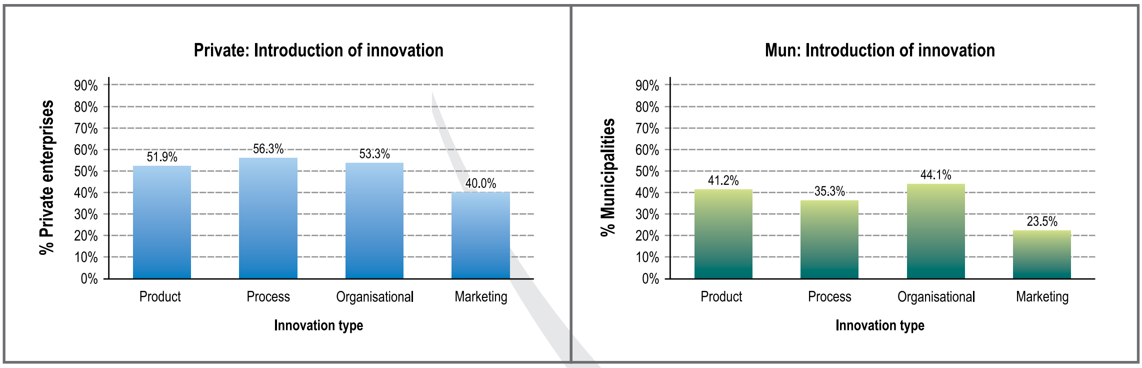


Figure 5.5: Introduction of innovation within the private and public waste sectors (DST, 2013)

Interestingly, the majority of new technological innovation (product and process innovation) being introduced into the private and public waste sectors, originates locally (Figure 5.6). An analysis of innovation within the waste sector shows that 60% to 67% of private waste companies are introducing local technological innovations, with 26% to 35% introducing innovations from abroad into the South African market (DST, 2013). The private waste sector showed a higher tendency than municipalities to introduce technological innovations from overseas, with 26.1% of private enterprises indicating that they had sourced their product innovations mainly from abroad, and 34.7% their process innovations. This is higher than the figure of 24.0% for the broader South African business sector, reported on in the South African Innovation Survey for 2008 (HSRC, 2011).

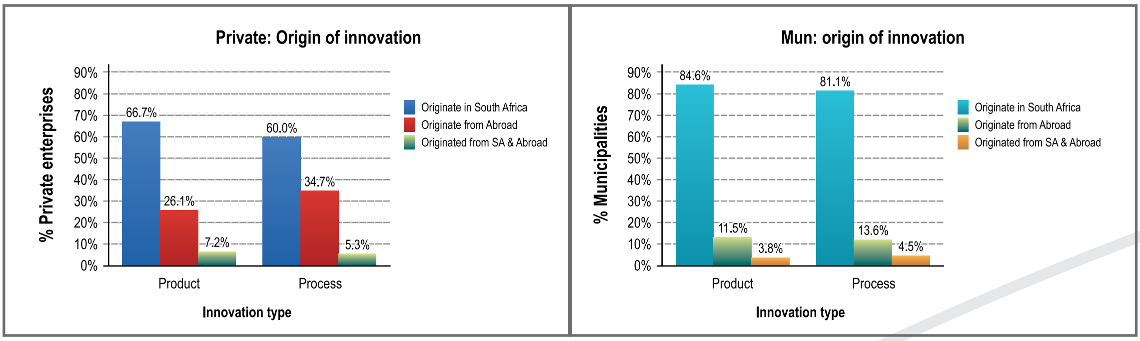


Figure 5.6: Origin of waste innovation within the private and public waste sectors (DST, 2013)

The availability of off-the-shelf waste technologies internationally is of benefit to the South African waste sector, where companies are able to 'shoparound' for the most appropriate technological solutions. It does however appear to have impacted upon the local investment in waste R&D, which is low at only 0.33% of the value of the sector (DST, 2013).

5.4.4.2 Local Waste Technology Opportunities

While 90% of South Africa's waste is currently landfilled, our waste streams hold significant potential for waste minimisation, followed by increased waste reuse, recycling and recovery. This potential lies both in increasing current recycling figures, as well as exploring new waste streams where recycling is low or non-existent. The CSIR has identified the following waste streams, as possible waste streams to target for achieving the goal of the South African Waste Roadmap for "a 20% reduction (by weight) in industrial waste and a 60% reduction (by weight) in domestic waste, to landfill by 2022, as measured against the 2011 National Waste Baseline for South Africa" (DST, 2012b).

- Organic waste (e.g. garden waste, food waste, agricultural biomass, industrial organics).
- Mining and power generation waste (e.g. residue stockpiles, slag, ash).
- Waste tyres.
- Waste of electric and electronic equipment (e-waste).
- Packaging waste (e.g. paper, plastic, glass, metals).

These waste streams provide significant opportunity given both the large quantities of waste generated in South Africa, as well as their potential for recycling and recovery. The Waste Roadmap, currently under development by the DST and due for completion mid-2014, will further explore where opportunities exist for local science, technology and innovation in the South African waste sector.

Domestic, commercial and industrial organic waste in particular provides opportunities for recycling and recovery technologies. Municipalities and business are investigating, and in instances implementing, alternative solutions in the form of composting and anaerobic digestion to deal with the organic fraction of municipal solid waste and agricultural biomass. Most of the larger metropolitan municipalities in South Africa are also currently looking at establishing large, high-temperature thermal EfW technology solutions, such as pyrolysis and gasification, through public-private partnerships with the private waste sector. However, due to a number of obstacles (See Section 5.4.5), no large-scale EfW technologies have yet been commissioned in South Africa.

As at August 2013, seven EfW clean development mechanism (CDM) projects were registered in South Africa, all associated with landfill gas recovery; this from a total of 56 waste management CDM projects which have been reviewed to date (DoE, 2013c).

5.4.5 Barriers to Local Technology Uptake in the Waste Sector

Many alternative waste technologies are readily available from local and international companies, ready for adoption and adaptation to South Africa conditions and waste streams. Yet the uptake of green technologies in the South African waste sector to date has been slow. Adoption of alternative technologies does not appear to be so much of a technology issue as it is a receiving environment issue (political, governance, societal, economic) (DST, 2012a). An analysis of current obstacles to waste innovation in South Africa showed that economic/financial and legislative issues were cited by both the public and private waste sectors as the two biggest constraints to waste innovation in the country (DST, 2013).

Alternative waste technology projects in the waste sector are currently being constrained by issues such as (pers. comm., industry representatives; SALGA, 2013):

- Ownership of waste by municipalities, who act as 'gatekeeper' to renewable resources.
- Public Finance Management Act and Municipal Finance Management Act issues regarding long-term contracting between the public and private sectors, and public-private partnerships.
- Artificially low costs of landfilling which make alternative technology options more expensive and unaffordable.
- Supplying electricity into the Eskom grid.
- Delays in approval of industry waste management plans.
- Licensing and approval processes for alternative waste management options required by the NEM:WA.
- The definition of waste which adopts a conservative, risk-based approach.
- Political will to prioritise waste within the municipal functions.
- Community resistance to certain technology options, e.g. high-temperature technologies.
- The lack of technical waste skills in many municipalities to appropriately evaluate waste technology options.
- The lack of reliable waste data.

Joining this global paradigm shift towards a circular economy is therefore going to require attention on a supportive and enabling environment for alternative waste technologies. Perhaps the problem in South Africa is that recycling and recovery are still viewed as waste management solutions, rather than resource and energy solutions.

5.5 Green Technologies in Sanitation

5.5.1 Introduction

The urban population will double in the next 50 years. It is foreseen that water scarcity will increase, energy requirements will soar and agriculture nutrients will be under pressure. Sanitation has a major impact on human health, water and energy usage and could play an important role in nutrient recycling for agricultural purposes.

Limitations of conventional sanitation include inadequate purification of more than 90% of wastewater worldwide leading to pollution and health risks, while using precious water. In many cases water used in conventional flush toilet sanitation is of a potable quality leading to more water being used for sanitation than drinking. Not only does this require a significant amount of energy, but also high costs pertaining to operation and maintenance of conventional wastewater treatment works.

In terms of the national average, the percentage of households without flush toilets or still using bucket toilets was 5.3% in 2012, which is an improvement from 12.3% in 2002 (StatsSA, 2013a). Government intended to provide access to water and sanitation throughout the country by 2014, and indications were that flush toilets were the means to achieving the sanitation targets. Given this significant task, the necessity of adopting alternative technologies increases when water shortages and high costs of sewerage are considered (Eales, 2010).

5.5.2 The Case for Green Sanitation

Farmers require millions of tons of fertiliser annually for growing crops and simultaneously millions of tons of fertiliser equivalent are dumped as waste annually. Sustainable sanitation can contribute to sustainable agriculture by using the nutrients in the sewage sludge to supplement fertilisers, turning the disposal of products into new products. The question is whether there is a single solution as an alternative to conventional sanitation. Green sanitation (also referred to as eco-sanitation) does not favour a particular technology, but embraces a philosophy of recycling resources. The question is whether urine and faeces can be made safe for crop production. The challenge therefore is to safely reticulate human-derived nutrients. In order to save energy, the case can be made for decentralised systems, incorporating cost-effective solutions and a holistic interdisciplinary approach. This opens up a wide range of sanitation options.

The most important short-term driver for improved sanitation is however public health concerns. A new mindset is required therefore, where wastewater is considered as a valuable resource rather than a waste. The challenges of such a new approach include minimising the introduction of pathogens from human excrement into the environment. System design should minimise health risks and maximise nutrient recovery. Recovered nutrients can be used to promote soil fertility and the improvement of agriculture and food security.

The main requirements of green sanitation are: compatibility with socio-cultural economic conditions, ease of use, being robust in operation, and making maximum use of locally available resources. This renders green sanitation options more complex than conventional flush toilet systems.

Essentially, three types of green sanitation designs are used, including urine diversion systems, dry sanitation systems and composting latrines. The design criteria of each and the advantages and disadvantages of each will not be discussed in detail since these have been reviewed previously (*Water Aid*, 2011).

Eco-sanitation options are often not successful because of the lack of demand from the user. The key question is, what would change the mindset and result in the household being prepared to spend money on sanitation options available? It seems obvious that health reasons could be a driver for behaviour change, but research has shown that it is not the case.

Research by the World Bank Water and Sanitation Programme has identified several other factors that motivate poor households to invest in sanitation (*Water Aid, 2011*). "These include:

- convenience and comfort;
- privacy and safety;
- for women and girls, avoidance of sexual harassment and assault;
- less embarrassment with visitors; and
- dignity and social status."

Many sanitation projects have failed due to a poor consideration of the socio-cultural sustainability of the system.

Simpson-Hebert and Wood (1998) have identified ten barriers to progress in sanitation, all of which are equally valid for the safe use of excreta and grey-water. "These include:

- lack of political will;
- low prestige, priority and recognition;
- poor policy at all levels;
- weak institutional framework and unclear distribution of responsibilities;
- inadequate and poorly used resources;
- inappropriate approaches;
- failure to recognise defects of current excreta management systems;
- neglect of consumer preferences;
- ineffective promotion and low public awareness; and
- women and children last."

5.6 Green Technologies in the Industrial Sector

5.6.1 Introduction

The implementation of green technologies in industries aims to minimise the use of hazardous materials and increase energy efficiency during a product's lifespan. The focus is on recyclable or biodegradability products and industry waste.

5.6.2 Implementation of Green Technologies

South Africa is a carbon-intensive economy due to its reliance on coal for energy production. Given that the industrial sector consumes nearly a third of South Africa's energy use and over 50% of its electricity, this sector presents a tremendous opportunity for implementing green technologies. To develop green industries in South Africa, the IDC has allocated R25 billion over five years (2010/2011–2015/2016). These funds were distributed via the Green Industries Strategic Business Unit (SBU), the purpose of which is to develop, grow and invest in green industries within the country. The focus areas are:

- Non-fuel-based green energy such as renewable energy.
- Energy efficiency and demand-side management.
- Emission and pollution management.
- Fuel-based green energy, i.e. waste to energy and co-generation.
- Biofuels, e.g. bio-ethanol.

South African industries have the potential to supply large amounts of electricity through co-generation onto the grid. Barriers to implementation are difficulties in getting agreements with Eskom and/or local municipalities, uncertainty about the future in terms of prices that will be paid for selling electricity to the grid and high wheeling costs, although in recent years there is evidence that there barriers are being overcome.

A R500 million Green Energy Efficiency Fund was launched between a partnership with Green Industries SBU and a German development bank (KfW). The aim was to encourage investment by local entrepreneurs on energy efficiency projects. R96 million was allocated to eight projects which ranged from co-generation to waste-to-energy, solar water heating and rooftop PV.

In the South African IPAP 2012/2013 – 2014/2015, green industries have been identified as one of the key sectors which will strengthen industrial policy interventions. Contributions to developing green industry in South Africa include:

- The Renewable Energy Independent Power Producer Procurement Programme (REIPPP), launched in August 2011 with the goal of reaching a capacity of 17.8 GW renewable energy generation by 2030.
- Increasing levels of local content with an emphasis on adhering to green principles.
- New regulations on the mandatory blending of biofuels.
- The Industrial Energy Efficiency Programme which was launched in November 2011.

The National Cleaner Production Centre, which was set up to primarily assist industry in becoming more resource efficient, is housed at the CSIR on behalf of the dti. The centre aims to assist companies and sectors to become greener while increasing competiveness, creating jobs and growth. It does this by creating awareness, technical interventions, advising, building local expertise and demonstrating successes.

The chemical industry in South Africa, through the Chemical and Allied Industries' Association (CAIA), subscribes to the Responsible Care programme, a global initiative of the chemical industry launched in 1985, which developed into the UN Responsible Care Global Charter of 2006. CAIA has over 150 members, including chemical manufacturers, traders and industry service providers. The Responsible Care programme looks at continuous improvements in health, safety and environmental performance of industries. The programme encompasses the development of green chemistry leading to more sustainable processes. For example, the Strategic Approach to International Chemicals Management, part of the Responsible Care initiative, has as its overall objective the achievement of the sound management of chemicals throughout their life cycle so that, by 2020, chemicals are produced and used in ways that minimise significant adverse impacts on human health and the environment[4]. The chemical industry thus reports annually against certain performance indicators, such as water consumption or energy consumed per ton of product.

PetroSA has embarked on a programme to import liquefied natural gas. Part of the rationale for this programme is that it may be possible to generate power near the coast using combined-cycle gas turbines. Not only are these far more efficient than pulverised-fuel power stations, but by siting them at the coast, they can use seawater for cooling, which is more efficient than dry cooling. They also save the transmission losses otherwise associated with generating power inland. The net effect is a marked reduction in GHG emissions for the same installed power.

The paper and pulp industry is a big energy consumer—the world's fifth-largest industrial user. The World Resources Institute set the industry's CO_2 emissions at about 500 million tons worldwide in 2005[5]. This industry is also a large consumer of water, with much of the water that is taken into the process being released back into the environment. Reducing water use leads to both lower chemical consumption, as well as reduced energy usage. Energy is used to make hot waste and steam for cooking wood chips, pulp washing and drying paper. Hence there is a possible win-win situation in terms of reducing energy and water consumption and increasing profitability of the process. South African paper mills do implement water recycling already. Paper mills and processing produce waste that can be used to generate steam and also produce waste steam. This could be used for co-generation of energy, which is currently not undertaken.

The South African sugar industry comprises 14 sugar mills, which are designed to be energy neutral. However, the mills could be operated in such a way that significant amounts of excess energy are produced, which could be converted to electricity and, in turn, fed into the grid.

[4] http://www.caia.co.za/index.php?pg=19http://www.caia.co.za/index.php?pg=19
[5] http://www.economist.com/news/business/21590965-technological-fix-proposed-combat-global-warming-roll-green-revolution

5.6.3 Future Developments in Green Manufacturing

The concept of green manufacturing includes both the manufacturing of greener products as well as the greening of the manufacturing process. Here we focus on the second aspect, namely the manufacturing process itself.

Reducing the use of resources, the production of waste and recycling and reusing can improve the profitability of a company and is also good for the image of the company. In order to achieve this, ways of redesigning and re-engineering, restructuring or retooling have to be considered so that the manufacturing process is more sustainable. A systems approach has to be used to look at the overall manufacturing process and this has evolved into the field of industrial ecology.

To this end, the concept of cradle-to-grave product design and production has been proposed as a way of considering the life cycle of the product so that aspects such as the manufacturing, the distribution and the disposal of the product can be holistically viewed.

Examples of technologies that might be implemented in future with a view to greening the manufacturing process could include:

- Methods of marking products, such as sensors, so that that life cycle of the product can be traced.
- New production technologies such as digital or additive manufacturing.
- Reconfigurable manufacturing systems.
- New materials such as composites or light weight alloys.

5.6.4 Future Developments in Green Chemistry

Global trends in R&D include the following:

1. Use of Renewable Feedstock

Renewable feedstock includes biomass, possibly waste, which may be generated through a number of approaches, such as:

- Thermochemical treatment (i.e. gasification) of the substrate to yield a simplified intermediate (typically syngas), which can then be used in fairly conventional processes to yield syngas-based chemicals. This approach is best suited for situations where biomass is being processed in any event (for food, paper, etc.), and where the final product can be sold at a significant premium as a result of its green credentials.
- Biological breakdown to a simplified platform, from which processing starts again. This covers classical fermentations to ethanol, as well as conversions to methanol, methane (anaerobic digestion), and new 'platforms' such as succinic acid, lactic acid, etc. which are coming increasingly into vogue. Typically, this is more efficient, but struggles to utilise the full range of available feedstock.

2. Using Biological Processes to do Transformations

The following are being considered:

- Using the inherent efficiency and selectivity of biological processes to convert syngas directly into ethanol or butanol or methane into methanol or ethylene. Typically when volumes are large, contamination is a challenge and conversion temperatures and pressures are low. The mild operating conditions may have advantages in certain situations, but are often problematic in terms of compactness, heat recovery or downstream separations from water.
- Using plants (algae, plants, etc.) to capture sunlight and process CO_2. (There are also some ventures into generating hydrogen, but this is still at an early stage.) The production of chemicals in this way will remain a challenge and will require either a green premium or a focus on products on the high-value end of the chemicals spectrum.
- Using biochemical processes to attack biomass and do the conversions discussed in the previous sections.

3. Developing Entirely New Products

This is an area where the pharmaceutical and 'flavours and fragrances' industries have led the way in finding useful compounds in nature that have not been created using conventional chemistry. This approach is struggling to take off in the more general industry.

5.7 Green Technologies in the Mining Sector

5.7.1 Introduction

Mining is arguably South Africa's most recognisable industry having made a major contribution to South Africa's economic development. According to Simpson (2012), the mining sector is less than a third the size of the country's manufacturing sector in terms of gross domestic product (GDP) contribution. It comprises about 60% of the country's exports and eight of the ten largest individual export categories are commodities. Mining plays an important role in the economic prosperity and social development of South Africans, particularly in rural areas, where mines are one of the largest employers.

The mining sector has a reputation as a major polluting sector, having many negative environmental and health impacts (Dexia, 2010), yet ironically, it is the key to the introduction of green technologies in many other sectors. The mining sector is the source of raw materials used, for example, in hybrid cars, modern wind turbines, energy efficient lights and motor vehicle catalytic converters. The negative impacts will need to be managed and balanced against the benefits that the mining sector offers to the broader economy and at the same time highlight the importance of sound environmental management within the mining sector itself and the value of green mining.

5.7.2 Green Mining

Green technologies have struggled to find traction in the mining sector as the industry is risk averse, according to a recent report released by Kachan & Co. (2013). However, changes are now taking place largely as a result of the promise of economic benefits from new developments in green mining. Other drivers of green innovation in mining technology according to Kachan & Co. (2013) are market volatility, rising costs, falling commodity prices, decreasing productivity, policy changes and social justice scrutiny.

Green mining involves finding innovative ways to minimise waste, improve energy efficiency, minimise water consumption and to rehabilitate landscapes. Interventions can be introduced at each stage of the mining process. For example, during the mineral extraction stage, various chemicals and reagents are used to extract minerals. These may include mercury, cyanide and sulphuric acid. After use, most of these chemicals are released into waters near the mines, leading to water pollution. Despite the use of tailings or pipes to dispose the chemicals, leakages do occur. Leaked chemicals, infiltrating the earth, could therefore pollute the groundwater. The chemicals can also make the soil unsuitable for plants to grow. The use of green reagents, which eliminate the use or generation of hazardous substances in the design, manufacture and application of chemical products, will alleviate the contamination of the soil. Greener reagents and chemicals are the technology of the future within the mining industry.

Other examples of green mining include the reduction of GHGs, selective mining approaches to reduce ecological footprint, the use of bioremediation in mine closures and the use of an environmentally friendly slag binder as an alternative to cement to shore up shafts to prevent collapse (Vella, 2013).

In South Africa, green mining initiatives are becoming an increasingly economically viable option for the industry. While it may be costly to comply with environmental legislation, the long-term benefits that a mining company could reap by going 'green' present a more viable option. Non-compliance with environmental legislation may result in the directors of the offending companies being held liable, companies shutting down, operation stoppages, delays or having licences revoked, large legal bills, imposition of penalties, and loss of investment, all of which can be avoided (Newman, 2011). High energy costs and pressures for sustainability are also triggering efforts to improve energy efficiency and investigate the use of alternative energy sources.

South African mining houses such as Anglo American Platinum (Amplats) and Sibanye Gold have both introduced green mining. Amplats has two pilot projects that have introduced platinum-based fuel cell-powered equipment into their underground operations and Sibanye Gold is capturing methane to generate electricity at one of its mines and feeding the excess back into the national grid[6].

[6] http://www.promethium.co.za/news/south-africa-innovates-green-mining-arena/

Box 5.1 presents green initiatives of Mintek (2013).

Box 5.1: Mintek and green technologies
The mining industry is responsible for using substantial quantities of water and energy, producing high CO_2 emissions and contaminating water resources. Mintek believes that there is potential to improve the efficiency of energy and water use in mineral processing, and hence has as its third strategic objective: Research and develop green technologies and processes to mitigate the impact of mineral development on the environment (Mintek, 2013).

Specific objectives are as follows:
- Water: Develop water efficient flowsheets to optimise water consumption and enable processing of ore bodies in water stricken areas.
- Energy: Develop energy efficient processes, flowsheets and control technologies that minimise energy consumption and carbon emissions.
- Waste: Develop technologies for treating and recycling waste in order to extend mineral resources and rehabilitate derelict and ownerless mine sites.

With regard to rehabilitation of mine sites, Mintek has managed a three-year programme valued at R90 million on behalf of the Department of Mineral Resources . The programme ended in March 2013 and resulted in the completion of 14 projects and the creation of 305 temporary jobs (Mintek, 2013).

5.7.3 International Perspectives: The Case of Canada

The importance of the mining sector in Canada's economy, as in South Africa, makes green mining innovation especially vital. Some lessons from Canada's experience are relevant. The environmental performance of the mining industry in Canada, which is built on a solid foundation of technological innovation, has greatly improved over the last few decades and has already produced impressive results. Some of their successes include the dramatic reduction of acid-related damage of mining activities as a result of new prediction, prevention and treatment methods. In addition, mine closure methods for both current and new mines have been improved, through a requirement for closure plans and financial assurances provided upfront.

In 2002, the Canadian government took a bold step by introducing the Green Mining Initiative. The initiative aims to encourage innovation and promote environmentally responsible mining practices at every stage of the mining life cycle. This $8-million initiative is led by Natural Resources Canada in partnership with federal and provincial ministries, as well as key stakeholders from industry, universities and non-profit organisations.

The Green Mining Initiative offers a holistic approach that addresses all steps in the mining process[7]. The approach is based on four broad pillars:
• Footprint Reduction.

[7] http://www.canadiangeographic.ca/themes/environmental_footprint/green-mining.asp

- Innovation in Waste Management.
- Mine Closure and Rehabilitation.
- Ecosystem Risk Management.

5.7.4 The Mining Sector and Rare Earth Elements in South Africa

An overview of green technologies in the mining sector would be incomplete without commentary on the potentially significant future role of South Africa in the production of the strategically important rare earth elements (REEs). REEs consist of 17 different metals that are vital for the production of green technologies (Table 5.1) (Jepson, 2012). Currently, China accounts for 97% of the REEs produced globally due to China's recognition of the strategic importance of REEs early in the 1980s and subsequent strong state support and competitive pricing. Interestingly, however, during the 1950s, South Africa was the world leader in REE production, and is currently at the forefront of global efforts to revitalise the REE industry in competition with China (Jepson, 2012).

Mintek has a good database around the recovery and refining of REEs, which was developed from the 1980s. More recently, REE processing has become a potential strategic project that would limit dependence on the supply of REEs from China. Based on these market developments, Mintek has been involved in major projects in South Africa, and southern Africa to develop cost-effective flowsheets for the recovery and refining of REE. A REE separation pilot plant will be operated during the first six months in 2014 to demonstrate a portion of the refining flowsheet. This work forms part of a larger initiative to establish a central REE processing facility in South Africa to facilitate the development of South African REE resources (Mintek, 2013).

There are two mines in South Africa that offer potential in this regard. The first is at Steenkampskraal in the Western Cape, which was operated as a thorium mine between 1950 and 1963, with REEs being mined as a byproduct. The mine contains high-quality REEs in the tailings above ground and is expected to create 100 jobs at the mine and a further 80 to 100 jobs at the separation plant. The second mine is focused on a much larger deposit in the Northern Cape, known as Zandkopsdrift, which is potentially the largest REE mine outside of China. Extraction and separation of REEs is technically more difficult here and the mine is likely to create fewer jobs than at Steenkampskraal, but importantly, the jobs would be created in an economically depressed area of South Africa (Jepson, 2012).

Table 5.1: Key green technology applications for rare earth elements (Jepson, 2012).

Rare Earth Element	Application
Dysprosium	Nuclear reactors, electric vehicles, lasers, future green technologies
Holmium	Generates strongest magnetic fields currently possible, lasers, nuclear reactors
Erbium	Fibre optics, lasers
Thulium	Few current applications, does not occur naturally
Ytterbium	Solar cells, optics, crystals
Lutetium	Petroleum refining, possible cancer treatment, x-rays, computer memory
Yttrium	Phosphors, many alloys, turbochargers, prosthetics, cancer and arthritis treatment
Scandium	Aluminium alloys for aerospace, guns
Lanthanum	Hybrid batteries, computers, fuel cells, electronic vacuums, petroleum cracking
Cerium	Glass polishing, solar panels, light-emitting diodes (LEDs), catalytic converters
Praseodymium	Aircraft engine alloys, super magnets, computerised axial tomography (CAT) scan machines, fibre optics
Neodymium	Electric cars, wind turbines, air conditioning, hard drives
Samarium	Permanent magnets for defence applications, cancer drugs
Europium	Red and green colours in TV sets, control rods for nuclear reactors, alloys

There are significant negative environmental impacts to take into account in REE mining. Poor environmental controls in China have devastated vast tracts of land. The mines generate acidic waste water, produce harmful gases, contaminate groundwater and produce radioactive tailings (Jepson, 2012). The environmental impacts of the separation plants that convert the mined ore into oxides are even greater than the actual mining process. It will be imperative to address these potentially negative impacts in revitalising the industry. Over and above its own REE mining activities, South Africa has the potential to act as a regional hub for the processing of REEs mined elsewhere on the African continent (Jepson, 2012).

5.8 Green Technologies in the Agricultural Sector

5.8.1 Introduction

The agricultural sector is one of the earliest sectors to apply green technologies such as recycling of waste for use as fertiliser (composting, manure application) and contributing to conservation of biodiversity in grasslands and savannas through sound management of livestock grazing. It is, however, also responsible for many negative impacts on the environment including contribution to GHG emissions; pollution of water resources and environment from agricultural waste; consumption of a large share of the nation's water resources; land degradation through overgrazing; and biodiversity loss due to irreversible conversion of virgin land into cropland. These factors give the sector a negative image. They, however, also present great opportunities for application of modern green technologies to improve production efficiency and reduce the negative impacts of the agricultural sector on the environment, while improving the livelihoods of rural communities and ensuring national food security. Green technologies are an integral part of a response to climate change impacts that are likely to have major consequences for agriculture, such as increase in weather extremes, highly variable rainfall patterns, uneven distribution of rainfall over the season, high temperatures and associated evapotranspiration and less reliable predictive ability of short term or seasonal weather forecasts which play a crucial role in planning farming activities.

5.8.1.1 Conservation Agriculture

Conservation agriculture involves no-till methods of cultivating crops at both large and small scale, leaving much of the crop stubble in the field and thus replenishing soil organic matter content. This form of cultivation improves conservation of water resources as there is always vegetation cover that mitigates evaporation of soil moisture. Conservation agriculture has other benefits such as tangible improvements in soil biology, colloidal humus and water-holding capacity of the soil. All these lead to critical improvements in water use efficiency especially in rain-fed farming systems and reduce fertiliser inputs and use of herbicides over time. Principles of conservation agriculture include minimal mechanical soil disturbance (no-till), permanent organic soil cover and use of diversified rotations between annual and perennial crops. There are case studies in South Africa that have demonstrated the success of conservation agriculture by both small-scale farmers and commercial farmers near Bergville, east of the Drakensberg Mountains in KwaZulu-Natal. Much research aimed at investigating strategies to give "more crop per drop", as requested by Kofi Annan in 2000, is supported by the Water Research Commission (WRC) in South Africa (Everson *et al.*, 2011).

5.8.1.2 Biogas Generation

A technology that has received considerable attention recently is the use of biogas for renewable energy generation. Livestock manure is used in biogas digesters that produce biogas, which is a cost-effective, environmentally friendly energy source and an alternative to wood, charcoal and coal-generated electricity. Biogas generation supports sustainable and integrated agriculture practice. It is one of the simplest sources of renewable energy derived from sewage, liquid manure from chickens, cattle and pigs and organic waste from agricultural food processing. Biogas generation can produce by-products such as the organic waste that can be used as fertiliser in crop fields. Biogas digesters capture and utilise methane (one of the most potent GHGs) directly and in the process reduce GHG emissions from livestock. The gas generated from biogas digesters is used for generating power for cooking, heating and lighting. The biogas system has been piloted in several communities in KwaZulu-Natal, Limpopo and the Eastern Cape through research funded by the Agricultural Research Council and the WRC amongst others.

5.8.1.3 Precision Agriculture

In the past, fertiliser applications, irrigation and herbicide applications were often haphazard, and low prices for inputs did not lead to economic losses associated with such wasteful practices. However, wasteful application of agricultural inputs is no longer economically viable due to substantial and sustained increases in input costs. The rise in the crude oil price has substantially increased fuel costs of farming and increases in nitrogen fertiliser costs driven by supply and demand functions and persistent shortages in phosphorus have driven fertiliser prices high. Fertiliser contributes between 30% – 50% of production costs for grain crop producers as production input in South Africa (*GrainSA Report*, 2011), largely as a result of the energy-intensive nature of fertiliser production (*Future Agricultures,* 2008). Global positioning systems (GPS) on tractors, planters and sprayers have resulted in more precise placement of agricultural inputs, resulting in less waste and greater productivity; coupled with GIS-linked soil testing (GIS pinpoints soil sample locations), it is possible for the farmer to increase fertiliser application on small sections of land identified as nutrient-poor, without over-applying nutrients on better-endowed areas.

Another area of significant improvement in precision agriculture has been the use of hydroponics (Kumar and Cho, 2014). Hydroponic farming is a method of growing plants using mineral nutrient solutions, in water, without soil or in an inert medium, such as perlite or gravel. This form of farming is useful for growing niche market vegetables and herbs, particularly when combined with integrated pest management (IPM) practices to produce crops that are certified as organic. In South Africa, there is potential for application under greenhouse conditions especially in extremely dry climates (Kumar and Cho, 2014). Hydroponics also saves water because it uses as little as 1/20th the amount of water a regular farm uses to produce the same amount of food. Thus, this technology has huge potential for saving water use in agriculture given that South Africa is one of most water scarce countries in the world.

5.8.1.4 Biotechnology

Biotechnology is the use of living systems and organisms to develop or make useful products, or "any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use" (UN Convention on Biological Diversity, Art. 2). Biotechnology might include genetic engineering of seeds to develop improved plant varieties, bioengineering to increase resistance to stresses such as water stress diseases and pests, and other environmental stresses (climate variability). While genetically modified (GM) foods have been introduced extensively in South Africa, there still exists caution about their impacts on the environment and human health in the long term. However, there is scientific consensus that there is nothing alarming in the use of GM foods based on studies conducted over at least two decades. South Africa has policies that govern the use of genetically modified organisms. It is unlikely, however, that these will address all the concerns that arise from concerned members of the public. The main reason the use of GM foods is growing internationally is that they are economical and can produce high yields under very challenging conditions due to the genetically engineering plant traits. The dire need to address food security will always make the use of GM foods a viable option for many countries in the foreseeable future.

5.8.1.5 Integrated Pest Management

IPM has dramatically reduced the quantities and toxicity of pest control measures for farmers adopting this approach. IPM emphasises the implementation of biological control strategies, such as the use of pheromones, predators and traps to control pests. This includes careful scouting for pests, monitoring pest presence and levels and identifying economic thresholds in order to determine the required IPM intervention. Where chemicals are used, the least toxic available compounds are used; it is often possible to target pests at their most sensitive stage, using fewer chemicals or lower chemical concentrations than would be required at other stages.

5.8.1.6 Organic Farming

The International Federation for Organic Agriculture Movement defines organic farming as a production system that sustains the health of soils, ecosystems and people. Organic farming relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with possible adverse effects. Organic farming methods include 1) crop rotation (incorporating legumes with nitrogen-fixing bacteria for nitrogen fertilisation of the soil); 2) use of compost to increase soil organic matter and specifically colloidal humus; 3) emphasis on creating aerobic conditions in the soil (through appropriate cultivation, irrigation and plant management); 4) mulching to improve water use efficiency, 5) no-till or reduced tillage to save energy and 6) natural pest management (using bio-control instead of chemical methods). Organic farmers or their associations attempt to support social interactions with consumers through participatory guarantee systems of quality management, third-party organic certification, and development of farmers' markets and community-supported agriculture schemes, where there is a direct link between producer and consumer.

The nutritional quality of many common vegetable crops has declined significantly over the past 60 years (Davis *et al*., 2004). Organic agriculture is seen as a means to restore the natural state of many food crops and thereby improving quality. Other benefits of organic farming include soil carbon sequestration, low or zero chemical residues, improved water use and energy efficiency, improved agro-biodiversity. The emphasis of organic farming is local production and thus it is important for farmers to use locally produced inputs (seeds, compost, biocontrol measures) and avoid dependence on expensive imported seeds, fertilisers and herbicides and pesticides. Conventional farming's protagonists argue that hi-tech approaches (precision farming, genetic engineering, appropriate fertilisation and crop protection, strategic irrigation and mechanisation) are all environmentally sustainable, and that although the inputs may require energy and cause pollution, the high yields per hectare reduce the effective carbon footprint of the production system.

5.8.2 Barriers that hinder Green Initiatives in the Agricultural Sector

The various green technologies that are critical to the agricultural sector have major stumbling blocks because they are nonconventional, innovative and cutting edge. This suggests a requirement for a higher level of skills than those required for conventional farming practice especially for areas like the precision agriculture, decision-making in use of biotechnology products and application of integrated pest management systems. There is also a lag in both production and financial return between when a farmer makes a change from one method of farming to another, whether it is a shift from conventional farming to conservation agriculture or organic farming. The generation of biogas involves reuse of manure from farm animals and can be a labour intensive exercise, depending on the size of the biogas generation capacity. There is also a stigma associated with use of some of these green technologies such as biogas generation and organic farming. Some farmers and communities view them as ‘going backwards’ and therefore their adoption can be problematic. What is usually required is a champion farmer or community leader who can demonstrate the success of the application of the technologies on their yield and income.

Energy costs associated with agricultural production are linked to increases in oil prices. These substantial energy costs can be reduced by shifting focus to alternative energy sources (such as biogas energy as discussed earlier). However, use of renewable energy (solar power and wind power), although not strictly an agricultural green technology, has potential to improve agricultural by cutting down costs of production substantially. Solar and wind are renewable sources of energy and following the initial hurdle of high capital input for installation, the actual cost of operation and generating energy far outweigh the costs. This may also reduce dependence of farmers on the central national electricity grid, thereby giving them more control over their energy generation. Innovative policy instruments that allow farmers to sell surplus energy to the central power grid can go a long way in incentivising the use of renewable energy in the agriculture sector.

Another set of challenges to adoption of some of the green technologies, especially biotechnology, is their likely threat or risks to biodiversity, the environment and human health. There are fears in society that genetically modified organisms (GMOs) will likely outcompete natural species should they be allowed into the wild due to the tolerance for extreme environmental conditions. There are also concerns about human consumption of GMOs and their likely contribution to human ailments. However, there is little evidence to support some of these concerns in scientific literature.

Lastly, development of green technologies requires enabling policy and regulatory frameworks. Absence of relevant policies and regulatory frameworks might also allow unscrupulous profit-driven individuals to cause great harm to the sector and the reputation of green technologies. Fast developments in technologies also require a responsive policy environment.

5.8.3 Concluding Remarks

This section has shown that the application of green technologies in the agricultural sector presents opportunities to improve production efficiency, reduce negative impacts on the environment and simultaneously contribute to sustainable livelihoods and food security. The focus has been on the application of green technologies to crops. The livestock sub-sector has not been considered and requires further investigation.

5.9 Green Technologies in the Information and Communications Technology Sector

The information and communications (ICT) sector has the potential to play a fundamental role in enabling system-wide benefits, primarily through efficiency improvements. South Africa's ICT Research, Development and Innovation Road-map (DST, 2013), passed by Cabinet in 2013 makes specific mention of green technologies and provides an enabling framework for the introduction of green ICT.

The ICT industry itself is responsible for only approximately 2% of global CO_2 emissions. Narrowly-defined green ICT, including data centres and IT infrastructure, is being introduced in many companies. However, it is the broader contribution of the ICT industry that is far more significant. "ICT solutions have the potential to be an enabler to reduce a significant part of the remaining 98% of total CO_2 emitted by non-ICT industries" (WEF, 2009). The ICT sector can bring together various systems, software, data and infrastructure to improve efficiencies, to reduce costs and to have positive environmental impacts, either directly or indirectly (WEF, 2009).

Examples include substituting physical goods and services with virtual alternatives, such as teleconferences, online shopping or e-books. Table 5.2 provides examples of areas where ICT can improve operational efficiency, reduce costs and minimise environmental impacts.

Table 5.2: Examples of Green ICT business functions (adapted from Vodafone and Accenture, 2009 and WEF, 2009).

Business Operations	Manufacturing and Distribution	Sales, Marketing and Support Services
• Smart buildings and smart metering – to improve energy efficiency and encourage end-users to reduce consumption • Virtual collaboration – to minimise travel requirements, therefore reducing emissions • Dematerialisation – introducing a paperless workplace through e-billing and e-filing • Data centre – improving data centre efficiencies • Procurement – ensuring procurement practices incorporate green requirements	• Smart manufacturing – optimise efficiencies and minimise raw material movement through ICT, as well as communication modules to high-value products to transmit maintenance status • Smart logistics – use ICT to map efficient transportation networks, communicate wirelessly with vehicles to optimise speeds and loads	• Sales support – provide online and mobile sales support, minimising consumer transportation costs and emissions • Product marketing – online advertising and mobile apps, reducing paper usage, as well as costs • Customer billing – e-billing and payments reduce consumer needs to travel to business • Field operations – optimise travel of support staff to increase efficiencies

One of the areas where ICT can make a major contribution to reducing carbon emissions is as an enabler to smart grids (Vodafone and Accenture, 2009). With South African electricity supply constraints and the low reserve margin, there is a need for a system that will assist in ensuring consistent and reliable electricity supply in the country. Smart grids can allow for control of peak hour demand, without having to increase generation capacity. Smart grids use digital technology to constantly monitor and manage grid characteristics to enable utilities and consumers to maximise efficiencies in how they create or use energy (Enerweb, 2011; Folly, 2013).

Smart grid technologies play an important enabling role for other green technologies, such as allowing for an easier integration of electric vehicles into the electricity load at lower costs, providing reliable energy supply to enable green ICT as discussed above, as well as allowing for an easier interplay of energy to and from the grid (Morgan, 2012; Vodafone and Accenture, 2009). There are many other benefits, including accommodation of all generation and storage options, and detection and response to routine problems (Enerweb, 2011; Folly, 2013).

A South African Smart Grid Initiative has been established recently by SANEDI to facilitate the roll-out of smart grids in South Africa.

5.10 Green Technologies in the Health Sector

The health sector has the potential to be one of the largest recipients of green technologies, based on the size of its annual budget (R268 billion in 2013/14). Green technologies can be implemented across the sector aimed at implementing energy efficiency and clean energy generation; reducing water consumption; reducing the volume and toxicity of waste and ensuring safe disposal of waste; ensuring safe disposal of pharmaceuticals; following green building design principles and procuring food locally. Telemedicine applications also offer potential, particularly in rural areas. Initiatives to green the health sector in South Africa are in their infancy but the sector presents many opportunities.

Health Care without Harm, an international coalition of more than 500 members in 53 countries, launched an initiative termed Global Green and Healthy Hospitals in 2011. The initiative aims to green the health sector and create a network of hospitals (Karliner and Guenther, 2011). The report provides a framework for hospitals and health systems to achieve greater environmental sustainability.

5.11 Green Technologies in the Transport Sector

5.11.1 Introduction

An effective transport system is a key driver of economic growth and social development. Hence, one of the strategic focus areas outlined in the NDP is the prioritisation of transport solutions that are safe, affordable and effective options. One of the main challenges of the transport sector is its contribution to GHG emissions. Based on 2011 data, transport is the third largest source of GHG emissions in South Africa (Figure 5.) (IEA, 2012).

Various modes of transport impact on GHG emissions differently. The environmental issues relating to air transportation, including airport operations, for example, are noise emissions and fuel burn. For maritime transportation, it is mostly fuel burn. With respect to rail, about 60% of South Africa's network utilises electric power, with the remainder reliant on diesel (Marsay, 2012). Rail transport generates lower GHG emissions, with the main concern being noise. Transport GHG emissions are largely due to road transport, which accounts for 87% of transport emissions. Clearly, road transportation is the sub-sector where the use of green technologies will have the greatest impact in terms of arresting GHG emissions. In this respect it is noted that South Africa conveys nearly 89% of all freight by road.

With increasing population, additional transport services and infrastructure will be required, placing even greater demands on the sector to reduce GHG emissions. A further consideration is the energy required during construction of transport infrastructure. Pavements are the most critical element of an efficient road transportation system, and innovation in pavement technology is the key to reducing emissions from the transport sector.

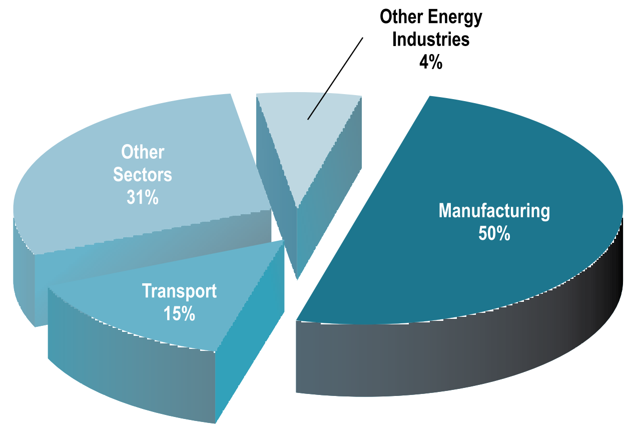


Figure 5.7: CO_2 emissions by sector for South Africa based on 2011 data (IEA, 2013)

5.11.2 Technologies for Green Transportation

There are many green technologies that have been implemented or are being investigated within the transport sector internationally, some of which are in use or under investigation in South Africa, while others have the potential to be acquired through technology transfer mechanisms. Those green technologies identified from various literature sources are listed in Table 5.3 (Agarwal, 2012; Endo *et al.*, 2010; Krohn *et al.*, 2009, Lamb *et al.*, 2011; FEHR, 2013; CAPSA 2011).

Table 5.3: Green technologies in the transport sector

Technology	Description
Biofuels	These are already showing promise; third generation biofuels may exploit fast growing algae to provide a drop-in fuel substitute.
Advanced composites	Future composites that will be lighter and stronger. Airplane manufacturers are starting to implement these.
Composite brake blocks	Technology being employed to significantly reduce noise made by freight trains.
Diesel hybrid	Technology being used in railcars. Railcars use both a diesel engine and regenerative brakes to charge an electric battery.
Electric power	Electric battery-powered aircraft such as unmanned aerial vehicles and vehicles are already in service. It is expected that as battery power improves, light aircraft and small helicopters will be battery powered.
Electric/hybrid	Use of electric, hybrid or hydrogen technology in vehicles.
Fuel cells	Hydrogen fuel cells will eventually take over from jet turbine auxiliary power units and allow electrics such as in-flight entertainment systems, galleys, etc. to run on green power.
Hydrogen power	Considered the ultimate green fuel. Early versions of hydrogen powered aircraft may be in service by 2050.
Inductive charging	On-line electric vehicle developed by the Korean Advanced Institute for Science and Technology. The electric vehicle picks up power from cables buried underground via a non-contact magnetic charging method. This provides a system that makes the range of an electric vehicle almost unlimited.
Industrial and demolition waste	Reduces environmental impact of using virgin materials in road construction.
Metal composites	New metal composites could result in lighter and stronger components for key areas in aircraft as well as vehicles.
Porous asphalt	Paving systems that allow runoff to pass through the pavement into a stone base, then into the soil below to recharge the groundwater supply.
Recycling	Re-use of materials. Currently being used extensively in all transport sectors, including road pavements. Initiatives are now underway to recycle up to 85% of an aircraft's components, including composites – rather than the current 60%. By 2050, this could be at 95%.
Rollpave	A concept developed from the Dutch 'Road to the Future' innovation programme. It is a prefabricated asphalt mat, approximately 30 mm thick that is laid on top of an existing pavement. It has sufficient structural strength to carry the design traffic and reduces traffic noise.
Soil pavement	Laid and compacted with natural soils and sands and chemical binders.

Technology	Description
Solar heat blocking pavement	A reflective paint capable of reflecting solar radiation is applied on the pavement surface, thus lowering the pavement surface temperature by about 10%.
Solar power	Power generation for road rest areas. Solar-powered aircraft could be practical for light sport, motor gliders. Hybrid sea vessels (wind/ solar).
Ultra-thin reinforced concrete pavement	Ultra-thin reinforced concrete pavement is highly suitable for labour-based construction; simple, inexpensive construction equipment is required and significant reduction in construction energy.
Warm mix asphalt	Asphalt surfacing which uses 15% of the recovered asphalt as a substitute for virgin materials and is able to reduce temperature by 30°C and CO_2 emissions by 20%.
Water retaining pavement	Purpose is the same as the solar heat blocking pavement, *viz.* to reduce pavement surface temperature. A specific paste with a water-retaining effect is infiltrated in the air voids of a porous asphalt pavement, keeping rainwater for several days, evaporation takes the heat from the pavement.

Recycling is a further green technology option that finds application in all categories of the transport sector, reducing consumption of material resources and impact on the environment. Aeroplanes, motor vehicles, railcars and pavements are being recycled and furthermore, materials used in their manufacture are environmentally friendly.

To have the greatest impact on emissions in the transport sector, roads should be designed and built to mitigate the effects of a range of environmental factors. Roads should be built to reduce traffic noise and GHG emissions by using appropriate surfacing technologies and low-carbon materials.

Captured solar energy can find use across the transport sector. It can be used to power light sport aircraft, hybrid sea vessels, lighting, signage on roads and even electric vehicles.

Against this background, it is clear that efforts are being made towards reducing GHG emissions by introducing green technologies in the transport sector. However, with increasing emphasis on the key role of transport, the stimulation of uptake of green technologies in the transport sector requires particular attention.

5.11.3 Stimulating Uptake of Green Technologies in the Transport Sector

Table 5.4 lists green transport solutions that have no implementation constraints. A first step towards achieving targeted and effective uptake is to ensure that there is a link between these green technologies and the projects that are supported under the Green Fund.

Table 5.4: List of "no implementation constraints" programmes (DPD, 2011).

Transport Mode	Cleaner Vehicles	Alternative Fuel	Roads Construction
• Urban mass transportation system: BRT (passenger) • Passenger rail (including high-speed trains) • Mass transportation system applications in freight (road or rail)	• Cars: hybrid or electric • Hybrid buses • Electric bikes • Bus retrofitting (gas) • Motor/vehicle efficiency	• Gas fuel technology • Biodiesel • Hydrogen fuel cell • Solar production of hydrogen for rail and public transport • Biofuel	• Roads upgrading programme using environmentally responsible technologies (green roads)

The Green Transport Centre – Energy Mobility Centre temporarily located at the CSIR, and being developed by SANEDI, is intended to stimulate innovative green technologies in the transport sector. It will test and demonstrate, for example, innovations in the development of alternate fuels and propulsion, as well as provide an incubator for new business development and technology partnerships which will assist small private sector partners to bring their designs to maturity and market readiness. The vision is to be a one stop facility for information sharing, technology development, technology demonstration related to use and testing of alternate fuels and vehicles.

A coordinated approach is necessary to stimulate green technology uptake in the transport sector (Rennkamp and Boyd, 2013). Links between universities and research councils should be strengthened for the purpose of supporting small business.

An appropriate funding mechanism to stimulate development and uptake of green technologies already exists in the form of the Green Fund. It is based on a model that recognises the need for continuous improvement, promoting green technologies, capacity building and research and policy development. Additional funding can be sourced through agreements between public and private financing institutions.

The institutional framework to stimulate uptake of green technologies also exists. What is required, however, is the strengthening of the institutional links in supporting small business. Many of the technologies are from international sources and require technology transfer agreements to facilitate uptake. Technology transfer is a factor that must be addressed in order to achieve long-term low-carbon development goals.

5.11.4 Potential Barriers to Uptake of Green Technologies

The green technologies listed in Table 5.3 are not locally manufactured. While implementation of such technologies can assist South Africa to leapfrog green technology development in the transport sector, facilitating technology transfer may be the binding constraint. Effective approaches to facilitating the transfer and uptake of green technologies are crucial.

Green technology development is a new sector in South Africa and the immediate need is to increase domestic technological capabilities. Lack of skills and limited technical knowledge are therefore other barriers to uptake.

Lack of local performance history of certain green technologies may make it difficult to penetrate the market. Due to differences in climatic conditions this may lead to low acceptability. In order to overcome this, a series of technology trials may be necessary before implementation or usage.

Inadequate policy implementation is a major potential barrier. A framework to implement a programme may exist but capacity to implement may not be available.

5.11.5 Concluding Remarks

South Africa's NDP sets out the country's long-term development vision, which includes that of a low-carbon economy. The high levels of GHGs emitted by the transport sector are an important constraint on the long-term growth potential of the South African green economy. Development and uptake of green technologies in the transport sector are therefore an important strategy. However, there are barriers to stimulating the uptake of green technologies. From an innovation perspective, these include problems in technology transfer, knowledge capabilities, market availability, technology acceptance and inadequate policy implementation. The framework for stimulating uptake exists, but institutional linkages require strengthening to support small businesses more effectively. Stimulation of green technology uptake will only be successful if this is achieved.

5.12 Green Technologies in the Building Sector

5.12.1 Introduction

The construction industry is the seventh largest contributor to GDP in South Africa at 3% (StatsSA, 2013b)and also a significant consumer of resources, especially materials, energy and water. Globally, it is responsible for about 50% of all materials used, 45% of energy generated to heat, cool and light buildings and a further 5% to construct them, 40% of water used (in construction and operation), and 70% of all timber products that end up in construction (Edwards, 2002). In South Africa, buildings account for 23% of electricity used, and a further 5% in the manufacturing of construction products (CIDB, 2009).

The construction industry has traditionally been a slow adopter of new technologies in general, mainly due to the perceived associated risks (Woudhuysen and Abley, 2004). The building sector, in particular, is reluctant to adopt new technologies due to potential buyer resistance (Woudhuysen and Abley, 2004). Thus the sector undertakes most of its work with conventional technologies.

Green technologies emerged at the time of the formal green building movement led by the British Research Establishment in the late 1990s. This saw the publication of green building systems such as the British Research Establishment's Environmental Assessment Method and the Passivhaus concept. Since then a number of new green building systems have emerged, including the Green Star® system, as adopted by the Green Building Council of South Africa.

Green technologies in the building sector can be defined as those technologies which reduce the impact of building on the environment through the development of more environmentally friendly materials and products, or through the generation and/or conservation of resources such as energy and water.

South Africa has a well-developed environmental policy framework and some of the policies impact on the building sector (CIDB, 2009; Van Wyk, 2003). Of the international commitments, only Agenda 21 speaks directly to the building sector, while within the South African policy and regulatory environment, the Green Building Policy, the Innovative Building Technology (IBT) Implementation Plan and the National Building Regulations and Building Standards Act directly address green building and green building technologies (See Chapter 3).

5.12.2 Uptake of Green Technologies in the Building Sector in South Africa

There is a wide range of green technologies currently available globally, although many of them could still be considered 'fringe' technologies insofar as they are not yet mainstreamed in the building sector. Some international building markets, such as the EU and the USA, demonstrate higher rates of adoption than other markets, including South Africa.

The uptake of green building technologies is summarised in Table 5.5[8].

[8]Note: the assessment of uptake is based on the personal knowledge of L van Wyk, CSIR, Pretoria. Very little data are available in South Africa to accurately quantify uptake of these technologies in South Africa.

Table 5.5: Status of green building technologies in South Africa

Technology	Description	Status in South Africa
Innovative building technologies	Non-conventional building systems, generally industrial and modular-based	Established as a fringe technology, but becoming more mainstream
Bio-based composite materials	Using natural fibres and resins to manufacture next-generation materials	Already in use in aeronautics and automobile industries; in R&D phase for building industry
Green infrastructure	Includes a range of technologies using natural systems to collect, treat and handle water and sanitation	Technologies available in South Africa but uptake low
Advanced cladding systems	High-performance building envelopes, generally modular and light-weight	Available but generally limited to high-end commercial developments
Chilled beams	Type of convection heating, ventilation and air conditioning system using a heat exchanger to heat or cool a space	Available but uptake low
Solar absorption chillers	Uses solar thermal energy to drive air conditioners	Only pilot-scale uptake
Demand-controlled ventilation	Provides the correct level of heating/cooling for the actual occupancy	Available and widely adopted within the commercial building sector
Dual-duct heating, ventilation and air conditioning systems	Provides separate ducts for heating and cooling with mixing boxes where required	Not widely used
Dual-wall facades	Combination of two or more high performance walling systems	Available but uptake low
Electrochromic glass	Changes light transmission in response to voltage, light or heat applications thereby controlling the amount of light and heat transmitted	Widely available but limited to high-end commercial buildings
Fuel cells	Converts chemical energy from a fuel into electricity through a chemical reaction with an oxidising agent	Fringe technology, not yet ready for large-scale adoption in the building sector
Geothermal systems	Uses geothermal energy for heating or cooling applications	Available but uptake low

Thermal energy storage systems (e.g. ice-based)	Allows excess energy to be collected for later use through mediums such as water, ice, and earth	Available but uptake limited to high-end commercial buildings
Passive ventilation	Using non-mechanised systems to ventilate buildings	Available, low-technology solutions widely adopted but higher-technologies uptake minimal
Underfloor air distribution	Relies on air displacement techniques	Available but uptake low
Solar energy	Uses sun energy to either heat a medium (solar water heaters) or to generate electricity (PV panels)	Widely available, adoption still fringe but showing rapid growth as costs come down
Co-generation and tri-generation	Generation of electricity and heat, mainly from gas	Limited uptake in areas with gas infrastructure
Heat pumps	Provides heat energy from a source of heat to a destination called a heat sink	Uptake increasing on the back of ESKOM incentives
Radiant heating/ cooling	Heats and cools surfaces rather than air which then radiate into the occupied space	Widely available and used, especially in residential sector
Wind turbines	Uses wind energy to generate electricity	Large-scale applications widely available and uptake growing; small-scale applications less available
Thermochromic glass	Regulates daylight automatically under the influence of light and heat fluxes	Available but uptake limited to high-end commercial buildings
Smart and intelligent systems	Uses sensors and actuators to respond to predetermined inputs	Available but limited to high-end commercial buildings

There have been some notable gains for certain green technologies, especially SWHs, heat pumps, and integrated building technologies (IBTs). The gains in SWHs and heat pumps have been driven by Eskom's energy demand-side management (DMS) strategy, where rebates have been provided to customers who have installed these systems. The gains in IBTs have, up until recently, been driven by customers seeking to reduce building time and cost; however, government's adoption of IBTs for its social infrastructure delivery programme is likely to accelerate growth significantly in the sector.

With regard to the uptake of green technologies in the building sector, these have, in the main, been restricted to energy efficiency in response to energy supply and demand pressures. The uptake of non-energy-related technologies has been slow.

5.12.3 Barriers and Opportunities in South Africa

There are a number of barriers and, by implication, opportunities, to the wide-scale adoption of green technologies in the building sector (Van Wyk, 2006).

i) **The delivery system** – the industry's delivery chain consists of many composite parts (complex), often operating in difficult and aggravating circumstances (complicated), involving multiple participants operating from inside and outside of the industry, resulting in a system(s) that may be assembled with competing new and never-ending variations and combinations. This multipartite structure results in unpredictable consequences, increasing risk to all participants without allocating liability to any.

ii) **Performance expectations** – unlike commodity consumers, consumers of building products have a very poor understanding of what constitutes building performance and therefore have low expectations. The tolerance level of building product consumers is far too high (perhaps because they believe that the industry is incapable of delivering better) and their understanding of risk far too low.

iii) **The knowledge base** – construction is a sector employing the fourth highest number of persons having no formal education, after agriculture, households, and mining. Generally construction skills are dominated by the most basic of manual skills, and since the construction sector is still largely dependent upon labour-based technologies, the net result is that the performance level of the construction sector is being determined by the low level of skill inherent in the sector as a whole.

iv) **Construction inspections** – enhancing the capability and competence of the certification and inspection bodies through accreditation, better information supply, and strengthening the enforcement powers of inspectors, will go a long way towards improving building performance.

v) **Construction warranties and service certification** – one of the main drivers for improving performance in the automobile industry was the provision of extended warranties to consumers. The building sector, by contrast, accepts very little responsibility for its performance. Part of this problem is related to (i) above.

vi) **Procurement environment** – generally the procurement of building products is driven by price alone, often to the detriment of long-term financial, social and environmental performance.

vii) **Social, environmental and economic issues** – the impact of building on natural resources, social well-being and cohesion, and economic viability is poorly understood both inside and outside the sector. Generally, buildings are measured in terms of the aesthetics with which they enclose basic shelter.

viii) **Quality-based regulatory regime** – essentially the building standards set a minimum standard for performance as compared to best practice. There is an international shift away from this approach to a performance-based approach, where regulation demands that buildings are safe, healthy and provide appropriate amenity, where amenity means something that contributes to human well-being.

ix) **Business acumen, management and innovation** – the economic uncertainty traditionally associated with the building sector (it is the sector where projects are halted as soon as any market distress is evidenced and re-started well after recovery has commenced) has resulted in a gradual but consistent loss of highly skilled personnel with a concomitant loss of business acumen, knowledge and ethics (i.e. collusion). The industry is dominated by a plethora of SMEs with very little working capital and a limited track record, high rates of business failure, and little evidence of process productivity improvement and very little attention paid to systematic performance improvement.

x) **Research and development** – R&D in the building sector significantly lags R&D in other sectors. Thus the industry is notorious for lagging in the uptake of new and innovative technologies.

5.12.4 Concluding Remarks

Very little progress will be made until the above systemic issues have been addressed: this will require a step-change in the industry, something that has been recognised in some international construction markets and where significant investment is made into changing the nature of the construction industry.

Part of the problem is located in the absence of responsibility; the industry is not accountable to any authority for its performance, unlike the automotive or aeronautical industries. The latter industries invest in R&D, design, manufacture, and remain liable for the finished products they produce, i.e., they retain sole ownership and therefore sole liability for their actions. The building sector is too disparate and diverse and therefore no sole responsibility is vested within the sector.

This can all be distilled into the following four challenges:

i) The challenge of globalisation and economic restructuring, requiring the strengthening of management skills throughout the public and private sectors.

ii) The challenge of sustainable development, requiring the strengthening of the links between economic restructuring (green economy), social cohesion (equity) and environmental protection (resilience).

iii) The challenge of a sustainable built environment system requiring high-performance facilities and infrastructure.

iv) The challenge of construction sector governance requiring an appropriate response to fiscal stress and institutional restructuring and increasing local capacity to manage change effectively.

A major priority should be to bring about a new total construction capability founded on customer orientation (addressing of unique processes), environmental design-based consciousness (ecological judgement), and a technology-driven (knowledge and expertise) delivery chain, including the clients, built environment professions, material manufacturers and contractors. This will result in a re-conceptualisation of construction delivery best practice away from determining what processes are required from a construction perspective to what processes are required for the optimal formation of immovable assets. Inherent in this refocus is the building of construction competence and product knowledge on the basis of post-completion evaluation, assessment and re-application to achieve immovable asset fitness-for-purpose.

5.13 Emerging Green Technologies

A number of sources have identified emerging technologies, amongst them the World Economic Forum (WEF) and McKinsey & Co.

A recent report by McKinsey & Co. (2012) has identified five emerging green technologies that could become game changers and make a major impact in the energy sector in the future. Given that the energy sector is such an important sector both globally and nationally, they are highlighted here as green technologies where innovation is developing rapidly and are identified as technologies to monitor closely.

Grid-scale Storage: Currently, only pumped-hydro or compressed air storage systems enable the large-scale storage of electricity in the grid. Innovations using flow batteries, liquid-metal batteries, flywheels and ultracapacitors could greatly expand opportunities and reduce costs.

Digital-power Conversion: The replacement of conventional high-voltage transformers by high-speed digital switches made of silicon carbide and gallium nitride offers opportunities to use 90% less energy, to use only 1% as much space and at considerably reduced cost.

Compressorless Air Conditioning and Electrochromic Windows: Air conditioners that dehumidify the air with dessicants rather than the conventional compressors and electrochromic window technologies that change the shade of the windows depending on the exterior-interior temperature difference offer opportunities to cut building heating and cooling costs. Costs of such technologies are expected to fall dramatically.

Clean Coal: CCS is currently very expensive but innovative processes under development could allow the capture of more than 90% of CO_2 at considerably lower costs. This technology could make coal with carbon sequestration more economically viable than renewable energy technologies.

Biofuels and Electrofuels: Second-generation cellulosic and algae-based biofuels are showing great potential. There is also research underway to supply CO_2, water and energy to enzymes to create long-chain carbon molecules that function like fossil fuels at a fraction of the cost.

The WEF's Global Agenda Council on Emerging Technologies[9] listed the top ten emerging technologies in 2013, of which those that can be considered as green technologies are highlighted below:

Online Electric Vehicles: These are next generation electric vehicles that receive power remotely from an electromagnetic field produced by cables situated underneath a road.

[9]http://forumblog.org/2013/02/top-10-emerging-technologies-for-2013/

3-D Printing and Remote Manufacturing: Objects that can be manufactured remotely through a process of printing layers of material on top of each other are showing great potential.

Self-healing Materials: The creation of non-living materials that mimic living organisms in their ability to repair damage extend the life of manufactured goods and hence reduce the demand for raw materials.

Energy-efficient Water Purification: These are new technologies that significantly improve energy efficiency in desalination or purification of waste water.

Carbon Dioxide Conversion and Use: These include new technologies that overcome the economic and energetic shortcomings of conventional CCS strategies. For example, one such technology is the use of biologically engineered bacteria that are able to convert waste CO_2 into liquid fuels or chemicals in solar converter systems.

Chapter 6

6 IMPLEMENTATION OF GREEN TECHNOLOGIES IN SOUTH AFRICA: DRIVERS, BARRIERS AND SOLUTIONS

6.1 Introduction

There are sound environmental, social and economic reasons to support the development, diffusion and implementation of green technologies in South Africa. Not only can green technologies help to address current environmental problems, but there are valuable economic benefits in the form of job creation, and alleviation of poverty and socio-economic inequality associated with their implementation. It is largely in response to global ecological and socio-economic pressures that countries around the world, including South Africa, have begun to focus on sustainable development agendas and green economic growth, in which green technologies play a central role.

The preceding chapters have outlined the national policy shift towards green growth (Chapter 3) and assessed the state of green technologies in various sectors across the country (Chapter 5). In some cases, reference has been made to sector-specific opportunities to increase the uptake of green technologies, and some of the sector-specific barriers that inhibit uptake. This chapter consolidates these findings to provide an overview of instruments available to promote the implementation of green technologies and the barriers to effective implementation, with a view towards providing a set of recommendations to improve the uptake of green technologies in South Africa. Many of the observations made, stem from a workshop hosted by ASSAf in September 2013 on Green Technologies: Drivers, Barriers and Gatekeepers, which was specifically aimed at opening up the debate on challenges experienced in the implementation of green technologies amongst a variety of stakeholders.

6.2 Instruments to Support the Development and Implementation of Green Technologies

Successful development, adoption and adaptation of green technologies depend on an enabling environment, which to a large extent is created by national governments. Hemraj (2013), following on from GTZ (2006), identified various categories of instruments that support green transition and which thereby assist in the development and implementation of green technologies, as follows:

- Regulatory instruments: including, for example, the development of norms and standards, which could mandate the uptake of certain types of technologies.
- Economic instruments: such as environmental taxes, fees and user charges, subsidies for the removal of environmentally harmful activities, and environmental financing and subsidies.
- Research and education instruments: providing further support for R&D and for education and training as new processes are developed.
- Cooperation instruments, such as technology transfer and voluntary agreements.
- Information instruments: which can help address information asymmetry and market failures through the provision of advice to consumers, reporting around sustainability and eco-labelling.

This framework (GTZ, 2006), with some slight modifications, is used as a basis to assess the status of various instruments to support green technology implementation in South Africa.

6.2.1 Policy and Regulatory Instruments

The state has introduced a number of policies relevant to the development and diffusion of green technologies (See Chapter 3). Some (e.g. Green Economy Accord, the Green Jobs Report) deal with the green economy directly, drawing attention to the goals, opportunities and challenges facing the green economy, and the central role of green technologies therein. Others (e.g. the NSSD and the NDP), recognise the importance of greening economic growth and increasing green innovation within the context of sustainable development and hence have an indirect reference to green technologies. It is clear that South Africa has an abundance of relevant policies and an enabling policy environment; any shortcomings in the implementation of green technologies are more likely to depend on failings elsewhere in the system or the lack of co-ordination, rather than on policy deficiencies, per se.

6.2.2 Economic Instruments

National Treasury began a policy process of environmental fiscal reform in 2004, introducing a range of financial instruments in the form of tax reforms, incentives and subsidies to support the growth of green enterprises (NT, 2006; Hemraj, 2013).

Examples of tax incentives include the DST's R&D Tax Incentive and the dti's 12I Tax Allowance Programme, which help promote green technology research, as well as the development and implementation of these technologies (Tshangela, 2013). Other environmentally related taxes include the electricity generation levy, the CO_2-based purchase tax on new motor vehicles, the general fuel levy, the incandescent globe tax, and the plastic bag levy. The DoE has recently introduced a tax incentive for businesses which improve their energy efficiency, where each kWh saved would receive a R0.45 tax deduction (Grewe, 2013). According to the KPMG Green Tax Index, South Africa ranks 13th out of 21 countries to use tax as an incentive to drive the green growth agenda; it ranks ahead of Australia, Singapore and Finland (Engineering News, 2013).

The REIPPP is an example of a recently introduced scheme, which adopts a version of a feed-in tariff scheme designed to help make green technologies more cost-competitive. Other schemes include the R4.7 billion solar water heating subsidy and the 70% annual subsidy for solar home systems (Modise, 2013). Subsidies play an important role in promoting greater green technology uptake (Hemraj, 2013).

In addition to these fiscal instruments, both the government and the private sector have made funds available to encourage green entrepreneurship, research and innovation, as well as the commercialisation and scale up of green technologies. Dedicated environmental financing mechanisms include:

- the Green Energy Efficiency Fund (managed by the IDC);
- the Drylands Fund (implemented by the Development Bank of Southern Africa (DBSA));
- the Green Fund (set up by the National Treasury with the DBSA as implementing agent). This is one of the key catalytic financing mechanisms to promote innovation in the field of green technologies and local manufacturing capacity. It provides support across the entire R&D value chain, from proof-of-concept to project implementation, particularly in the so-called 'valley of death', where funding is typically scarce and projects are still high risk. Most of the funds are channelled into pilot or demonstration projects (Mohamed, 2013). With an initial allocation of R800 million from National Treasury, the Green Fund was allocated R1.1 billion over three years (effective April 2012). At the time of writing, two rounds of proposal calls had been completed. In the first call, 590 applications worth R10.9 billion were received and in the second call, 155 applications worth R1.6 billion were received (Mohamed, 2013). Funding has been approved for 22 projects to date and the first disbursements were made in February 2013. The successful projects cover areas such as renewable energy and energy efficiency, waste beneficiation and waste to energy, waste water treatment and rainwater harvesting and smart grids. Most of the applications received were from the waste sector, followed by low-carbon energy and biofuels. The private sector and small and medium enterprises (SMEs) based in Gauteng made up the bulk of applications (Mohamed, 2013);
- the National Implementation Entity for the Global Adaptation Fund (implemented by the South African National Biodiversity Institute);
- the dti's Manufacturing Competitiveness Enhancement Programme (MCEP).

These economic instruments aim to support cleaner environmental projects, in line with national policy objectives, as well as mobilise additional funding from various sources (Hemraj, 2013).

Over and above national funding, international funding is available for green technologies. These include the Green Climate Fund and funds accessed through the Global Environmental Facility and the carbon market financing through the CDM.

6.2.3 Research and Education Instruments

Central to successful implementation of green technologies is a human resources base with the relevant knowledge, expertise, skills and values to support the green transition. Rapid changes in the environmental sector, and the green economy and green innovation more specifically, have meant that skills development has not kept pace, with the result that there is a skills development lag (DEAT, nd). It is widely recognised, for example the UNEP Green Jobs report (UNEP and ILO, 2008), that employment will change as economies green. In some cases additional jobs will be created, necessitating new skills, in other cases, jobs will be eliminated or transformed.

There is a need to define the core competencies across the full spectrum of professionals required to support technological innovation and to meet the demands of the green jobs. The Human Capital Development Strategy: Environmental Sector (2009 – 2014) of the Department of Environmental Affairs (DEAT, nd) confirms the urgent need to attend to the human capital development needs in the environmental sector more generally and provides a useful starting point for a more focused strategy aimed at human capital development needs for the development and implementation of green technologies. Such a strategy would of necessity address not only education and training needs across the entire system from primary to tertiary level, but would also focus on R&D needs.

6.2.4 Co-operation Instruments

Two categories can be identified:

- Technology Transfer: involves the acquisition of technologies from other countries, i.e. either through north-south or south-south transfer. Technology transfer options include bi-lateral and multi-lateral agreements; cooperation with international development cooperation agencies; establishment of technology transfer institutions; creation of local markets for environmental technology and support for pilot projects. In terms of creating local markets, the CDM can be classified as a 'cooperation' tool to facilitate technology transfer and capacity building between parties in developed and developing countries in response to climate change. Another mechanism aimed at accelerating technology transfer and assisting developing countries is the Climate Technology Centre and Network (CTCN), which is currently hosted by the CSIR in South Africa. The CTCNs were established as the operational component of the UNFCCC Technology Mechanism.
- Voluntary Agreements: involves firms, industries or sectors voluntarily committing to improvements in their environmental performance by setting their own targets, and monitoring and enforcement systems. Examples in South Africa include the Green Economy Accord and the Energy Efficiency Accord. Another is the agreement between government and industry with respect to the plastic bag problem. A suite of policy instruments was used, including: regulation of the minimum thickness of plastic bags, disclosure and transparency of the costs of plastic shopping bags, regulation of the type and amount of ink to be used for printing on bags, promoting a market for recycled materials, imposition of the plastic bag levy and prohibiting plastic bag imports. A further example is the chemical industry's Responsible Care programme or the voluntary uptake of ISO 14000.

6.2.5 Information Instruments

Various initiatives offering technical and business advisory services act as important drivers of green innovation. For example, the NBI has launched the Private Sector Energy Efficiency project that aims to provide support and advice to business (Grewe, 2013). The Climate Innovation Centre (CIC) located at The Innovation Hub in Pretoria is an innovative model aimed at accelerating locally owned and locally developed solutions to climate change (Mbileni, 2013). The CIC model was conceptualised by the World Bank's InfoDev Climate Technology Programme and offers an integrated set of services, including policy support and market information services, to technologists, entrepeneurs, start-up companies, SMEs and industry.

The CIC has a specific mandate to promote awareness of green technologies among historically marginalised groups and to facilitate their participation in the programme. It also aims to facilitate interaction and information exchange among current players in the 'climate innovation ecosystem' (Mbileni, 2013) and to gather information on stakeholder needs to refine CIC activities.

One of the initiatives supported by the CIC is Ecovest Holdings (Pty) Ltd, a South African company that markets four leading products; namely, ECOlite, ECOvision, ECOcool and an ECOstove (Ecovest Holdings, 2013). Importantly, these various solar-powered and rechargeable household appliances are produced using 70% locally made materials, and they are sold at competitive prices. In order to distribute the products, Ecovest Holdings has adopted a distribution model that uses local 'Spaza' shops as vendors to trade the goods. These vendors form cooperatives to ensure collaboration between shop owners. Local young people are trained to work as technicians for installation, as well as in sales and in the repair and maintenance of the products (Mbileni, 2013). To date, Ecovest Holdings has supplied 600 million Africans with household products that are able to meet their basic needs (Ecovest Holdings, 2013).

6.3 Barriers to Development and Implementation of Green Technologies

While recognising that many steps have been taken to provide an enabling environment for the uptake of green technologies (See Section 6.2), there still exist a number of barriers that inhibit innovation and stand in the way of more effective implementation of green technologies. Barriers that were highlighted at the ASSAf workshop on Green Technologies: Drivers, Barriers and Gatekeepers are discussed below.

6.3.1 Institutional Challenges

The first set of barriers, broadly referred to as institutional challenges, pertains to the lack of a coherent policy framework to support green technology development and diffusion in South Africa. There is rather a proliferation of policies, sometimes with conflicting goals (See Chapter 3), and in some cases a lack of policy certainty.

There are a large number of government departments with responsibilities to promote the green economy as noted by Montmasson-Clair (2012) and summarised in Table 6.1. Over and above these departmental responsibilities there are many other departments (e.g. mining, agriculture, forestry, fisheries, transport, housing and local government) that have indirect responsibilities chiefly through the creation of jobs.

Table 6.1: Responsibilities of national government departments with respect to green issues (after Montmasson-Clair, 2012)

Department	Responsibility
Presidency (advisory powers only)	National Planning Commission
Economic Development Department (has direct control over the Industrial Development Corporation and the Development Bank of Southern Africa)	New Growth Path and green economy
Department of Trade and Industry (has to rely on other departments to implement measures aimed at green industries)	Support for green industry
National Treasury	Environmental fiscal reform (green taxes and subsidies which support both green industries and the greening of the economy as a whole)
Department of Environment Affairs and Tourism	Responsible for the protection and restoration of ecosystems and the setting of environmental standards (e.g. for pollution or emissions)
Department of Energy	Responsible for issues relating to fossil fuels and renewable energy
Department of Water Affairs	Responsible for issues relating to water
Department of Science and Technology	Responsible for technology policy and R&D

Regulatory certainty, for example, a clear directive on issues such as carbon pricing and the continuity of funding via the REIPPP, is needed to avoid chasing away investors. Furthermore, policy direction is required in relation to the future use of shale gas and nuclear energy (Nassiep, 2013).

6.3.2 Government Bureaucracy

Complex and lengthy government processes, and a lack of political will, are in some cases delaying and even preventing green investment and the implementation of green projects. Examples presented at the ASSAf workshop include BMW's Tshwane Landfill Gas project, which aims to provide renewable energy to the company's Rosslyn plant, thereby reducing energy costs and carbon emissions. The project began in 2008 but has suffered serious delays due to difficulties in obtaining legislative approval and licences from local government (Viljoen, 2013). The proposed green technology manufacturing cluster in Atlantis in the Western Cape is another example of where it was reported that inefficient government processes have hampered green growth. In this case, the project set out to manufacture wind turbine components in an economically depressed area, thereby boosting growth and employment. The initiative has not materialised however, allegedly partly due to restrictions imposed by the Municipal Finance Management Act (MFMA), which has complicated the process (Du Plessis, 2013). The timeframes, processes and requirements of the MFMA have in some cases deterred investors. However, on a positive note, many examples exist of innovative green technologies which have been introduced by the eThekwini municipality (Durban) in the field of water and sanitation and which have succeeded despite MFMA constraints (Moodliar, 2013). Lessons in this case are early engagement and a partnership approach between the local municipality and National Treasury.

6.3.3 Skills Shortages

Many stakeholders have referred to the frustration experienced in dealing with officials, particularly local government officials, who lack the skills to provide the necessary support to green projects and enterprises. Implementation takes place at local level and given the range and sometimes complex nature of green technologies, it is essential that all government officials, including those at the local level, are sufficiently skilled and empowered to take decisions that will shape green growth.

However, the notion of skills shortage goes far beyond this practical experience with implementation and is often cited as a major impediment to innovation in countries (TIPP, nd), with South Africa being no exception. A useful OECD report (OECD, 2012c) addresses the matter of a strategic approach to skills policies, with some reference to green technologies and equipping people for green jobs. It is noted that the acquisition of green skills is likely to be a slow process and the OECD report concludes that top-up training will be necessary.

It is acknowledged that there is no simple solution to fostering an innovation-friendly environment as innovation requires a broad mix of skills. The formal education system has an important role to play, requiring a balance between content knowledge and innovation skills, which fall into three categories: technical skills; skills in thinking and creativity; and behavioural and social skills (TIPP, nd). Entrepreneurship programmes are acknowledged as important, as is pedagogy to encourage problem-based learning, as well as assessment instruments that value creativity. Mobility of people is also regarded as valuable for developing innovation skills in a globalised world, and over and above the role of the formal education system, the creation of an environment of lifelong learning in companies and organisations is considered important. In summary, policies to promote innovation should focus on: education policy; life-long learning policy; incentives to develop innovation-friendly organisations; and the facilitation of people mobility (TIPP, nd).

6.3.4 Intellectual Property Rights Barriers

Intellectual property rights (IPR) are widely recognised as a potential barrier to technology transfer (DST, 2007b) and a controversial issue. Developing countries generally can not afford the high costs of obtaining advanced technologies from multinational companies, usually located in developed countries. It is argued by some that in view of the need to promote technology transfer of green technologies as a public good to support global environmental sustainability, there is an urgent need to promote affordable access, in a manner similar to achievements with respect to HIV/AIDS drugs (Notaras, 2011). To date, the World Intellectual Property Organisation (WIPO) has been unable to establish such a global agreement.

6.3.5 Poor Track Record in Technology Transfer

Technology transfer can greatly facilitate access to green technologies. South Africa has to improve its record greatly insofar as technology transfer is concerned. One of the main market mechanisms designed to transfer technology is the CDM of the Kyoto Protocol and yet South Africa's involvement in the scheme has been dismal (ASSAf, 2011b), in contrast to other developing nations such as China.

Technology transfer should not be about identifying a shopping list of green technologies that can be imported. Prioritisation is critical as was discussed in Chapter 2. First, the green technology transferred should link to the local context, and align with South Africa's development needs and green growth strategy. In essence, there needs to be a socio-technical fit. Second, technology transfer is more than the transfer of hardware. It also includes knowledge transfer and even more importantly, innovation capacity (African Development Report, 2012a) (Figure 6.1). Innovation capacity is the knowledge required for generating and managing technological change and explains the direct relationship between innovation capacity and the flow of technologies.

Technology needs assessments, as required by the UNFCCC, are pivotal in assisting targeted and appropriate technology transfer as was discussed in Section 2.3, where it was used as a means of identifying priority technology needs. South Africa's technology needs assessment is currently being updated (pers. comm. H. Roman, October 2014). Further information related to technology transfer is presented in Box 7.2 in Section 7.3.5.

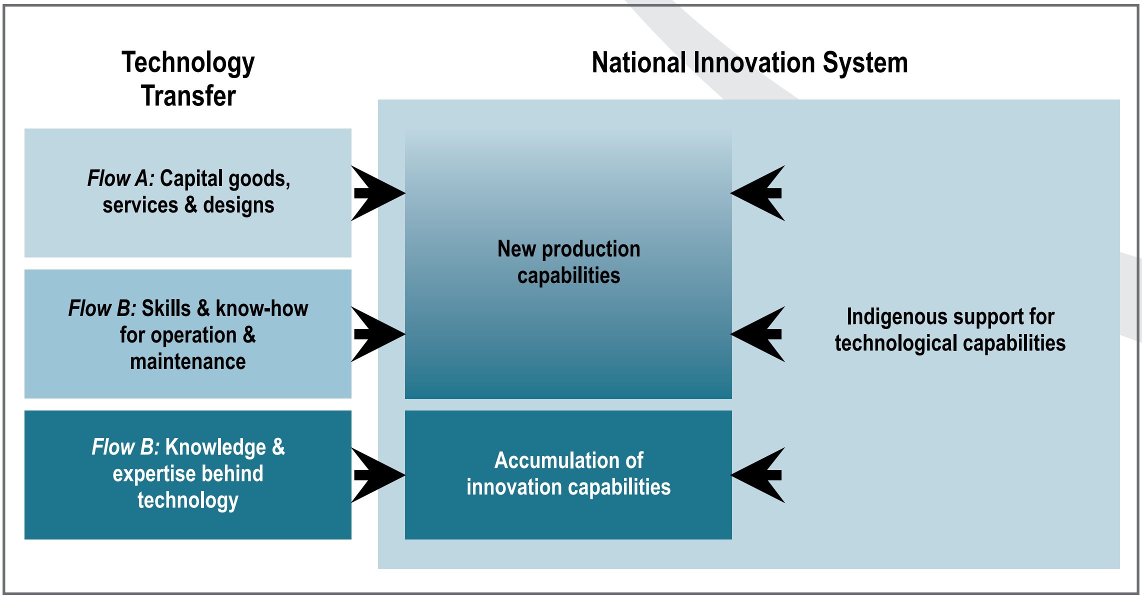


Figure 6.1: Flows of hardware and knowledge in the technology transfer process and their contribution to different types of new capacity (African Development Report, 2012a)

The absence of a robust innovation system is one of the foremost reasons that some green technology transfer schemes (e.g. the CDM) have failed in many developing countries. A fundamental requirement for successful green technology transfer is investment in the National System of Innovation (NSI), a requirement that would apply to South Africa as well.

There are some unique elements of green technologies that distinguish them from other technologies and therefore necessitate special consideration. For example, benefits derived from green technologies are a public good and are not market-driven. Furthermore, green technologies are often at the early technology development stage and may require further testing in new environmental, social and economic circumstances, leading to higher costs. Hence they may require greater policy intervention to facilitate transfer and uptake (African Development Report, 2012a).

6.3.6 Financial Barriers

While some progress has been made by the state to address funding (e.g. the Green Fund) that covers the so called 'valley of death', the supply of funding clearly does not match the demand (Mohamed, 2013). Green technologies require not only high R&D investments initially, but continued funding to ensure the commercialisation and scale up of these technologies. Given the level of investment, the substantial risks, and the slow, uncertain economic returns, both the state and the private sector are understandably hesitant to invest in green technologies. Access to finance is critical to green technology innovation and deployment.

6.3.7 Lack of Market Information

In South Africa, there is a lack of awareness and information about markets and trends, and a gap between the research environment where technology generation takes place and the market. Awareness of market needs will provide greater focus to innovation in South Africa.

A related aspect is the under-developed demand for green technologies amongst the South African public and the need not only to actively create markets but to better understand how to change human behaviour (See Chapter 8).

6.4 Overcoming Barriers: Roles of Government and the Private Sector

A recent OECD report (OECD, 2012c) provides evidence of a strong link between policy and the development and diffusion of green technologies. While innovation is determined largely by a country's innovation capacity, favourable policies can encourage local innovation and technology transfer. The role of government is not only to set policy but also to provide leadership and direction. Government should establish policies and provide incentives to stimulate the market, bearing in mind that government intervention may be required to create a market. In addition, their responsibilities include raising public awareness, providing appropriate education and training to support the development and implementation of green technologies, and providing the necessary advisory infrastructure to support implementation (CAETS, 2013).

Public financing is critical, with government funds being used to leverage private sector funds (CAETS, 2013).

Private sector involvement is also vital, particularly at the commercialisation stage. Partnerships between government and the private sector are important as industry needs insights into future government policy changes, technological innovations and new market opportunities (CAETS, 2013).

6.5 Concluding Remarks

Given the importance of green technologies to supporting green economic growth, it is essential to identify the barriers that impede their development and diffusion. Overcoming these barriers is crucial, but it is also equally important to reflect on, and learn from, successful green technology initiatives.

In summary, some of the learning points from the ASSAf workshop on Green Technologies: Drivers, Barriers and Gatekeepers and the discussion in this chapter, include:

- Ensuring a coherent policy framework.
- Ensuring regulatory certainty.
- Encouraging investment in green technology innovation across the various stages of development, from R&D to commercialisation.
- Promoting green technologies amongst consumers and encouraging a shift in behaviour patterns.
- Taking into account local capabilities to increase competitive advantage.
- Streamlining bureaucratic processes to fast-track green innovation and project implementation.
- Facilitating public-private partnerships to pool resources.
- Supporting localisation.
- Providing adequate financial instruments.
- Providing greater business support to emerging and established green enterprises.
- Building skills and capacity to foster innovation and facilitate a greater uptake of green technologies.
- Investing in infrastructure to support emerging green technologies.

These will be taken forward when making recommendations in the final chapter of this report.

Chapter 7

7 GREEN TECHNOLOGIES AND THE BUSINESS SECTOR

7.1 Introduction

Like many emerging industries, increased uptake of green technologies requires support from both the private and the public sectors. As a main contributor and user of green technologies, business has an important role to play. Business is faced with the challenge of reducing pollution, waste and resource consumption to minimise environmental impacts, while at the same time continuing to grow and increase profitability, and acting as a stimulus for innovation in the private sector (Gunningham and Sinclair, 1997; UNGC and Accenture, 2013). The focus of this chapter addresses the key role for the business sector in South Africa in terms of green technology development and uptake, the challenges and opportunities around diffusion of green technologies and then finally, explores opportunities for enhancing the role of business in green technology implementation.

7.2 Global and Local Trends in Green Technologies in the Business Sector

Businesses are becoming increasingly involved in green technology development and adoption. According to the Ernst and Young (2011) Tracking Global Trends report, green technology is viewed by business as a key area to gain competitive advantage and was identified as one of six key long-term developments shaping the business world. Leading companies are beginning to realise the commercial opportunities of green technologies and are starting to incorporate green technologies into their growth strategies. The UN Global Compact-Accenture CEO Study (UNGC and Accenture, 2013) also found that leading chief executive officers (CEOs) view technology and innovation as one of the key themes to achieve transformation and secure business sustainability. The 'clean technology (cleantech) revolution' is predicted to be the second industrial revolution and companies are being urged to act fast to ensure long-term sustainability (Pernick and Wilder, 2007).

While the scope of green technologies covers a wide range of sustainable technologies in various sectors (See Chapter 1), the largest proportion of clean technology is made up of energy-related technologies (51% in 2013). Recently the focus has shifted from renewable generation in 2010 to energy efficiency in 2013 (Cleantech Group and WWF, 2014).

According to the Clean Economy, Living Planet report (WWF and Berger, 2012), the global clean energy technology market has grown 31% per annum between 2008 and 2010.

In terms of investment in cleantech, Figure 7.1 illustrates global venture capital expenditure in cleantech from 2008 to 2013. Over this period, investment in cleantech declined from a peak in 2008 at €6 billion, declining in 2009 due to the global economic recession and peaked again in 2011 at over €7 billion. The current decline in investment may be attributed to gradual maturation of green technologies, requiring less investment.

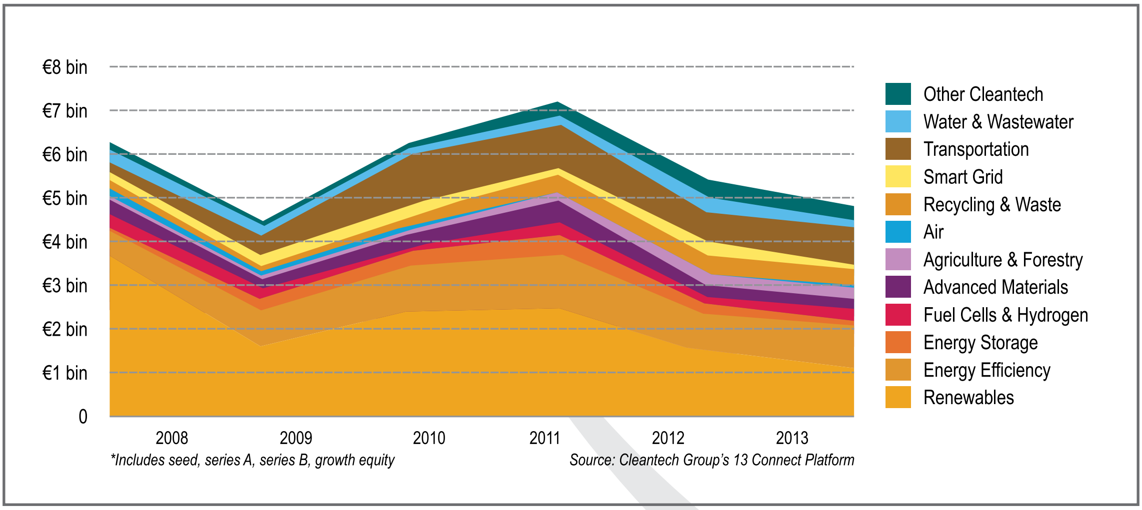


Figure 7.1: Cleantech venture capital investment in green technologies 2008 – 2013 (billion €) (Cleantech Group and WWF, 2014)

The report also identified those countries that are characterised by creativity and innovation in green technology, and those that have stimulating environments for companies in the industry, either through public policy or private funding. The top ten leading countries in green technology are Israel, Finland, USA, Sweden, Denmark, the UK, Canada, Switzerland, Germany and Ireland, according to the Cleantech Group and WWF (2014).

Developing country governments are trying to create enabling environments for companies involved in green technologies and are pursuing a variety of different cleantech development paths to achieve relative advantage. Brazil, a country known to be a renewable energy pioneer due to its large-scale hydropower and ethanol production from sugarcane, is now diversifying to small-scale hydro, wind and solar power and is also looking at harnessing energy from feedstocks, such as sugarcane bagasse owing to population pressures and energy disruptions due to droughts. India has singled out solar power as a key green technology to develop and has set targets in their National Solar Mission. China is also viewed to be an emerging clean energy leader, allocating 37% of its US$586 billion economic stimulus plan to cleantech, primarily renewable energy and smart grids (Ernst and Young, 2011). While Brazil, India and China feature 25th, 21st and 19th respectively, in the Global Cleantech Innovation Index, South Africa is ranked 29 out of the 40 countries (Cleantech Group and WWF, 2014).

South Africa is one of the most carbon-intensive economies globally, and national government has committed strongly to transitioning to a green economy and being a clean technology leader. However, like many developing countries, South Africa has been slow to develop and adopt green technologies (James, 2013) despite much enabling legislation as noted in Chapter 3. The implicit assumption embedded in these policy documents is that the systems, such as financial, infrastructural, resources and skills, required to be a technology leader are in place and work efficiently in all respects (NBI, 2013a), however, in many instances this is not the case.

According to the Cleantech Group and the WWF (2014), South Africa has below-average scores for most components of the Cleantech Technology Index including the general innovation drivers, cleantech-specific innovation drivers, emerging cleantech innovation and commercialised innovation. The score in Cleantech-specific drivers is slightly better due to favourable government policies.

7.3 Drivers of Green Technology from a Business Perspective

To promote the role of business in green technology development and deployment, it is important to understand the drivers of green technologies. In general, one of the main drivers from a business perspective, especially in the South African context, is the economic incentive of cost savings on the energy bill (CDP, 2012). With increasing fuel and electricity prices, coupled with an increasing demand for energy as the economy grows, companies are beginning to realise the importance of reducing energy consumption. By implementing various green technologies, companies are able to reduce or at least contain their operating costs (CarbonTrust, 2012).

In addition to increases in fuel and electricity prices, prices of other resources are increasing, as a result of population growth and higher demands for environmental resources. Combined with environmental risks and climate change impacts, such as water constraints, this means that resource pressure is expected to increase (Accenture and Barclays, 2011; UNEP, 2012c). These environmental factors are, in turn, constraining production especially in the agricultural sector, impacting on a number of supply chains that are dependent on the agricultural sector (IPCC, 2014). Companies that adapt to these changes sooner ('first-movers') will have a competitive advantage over similar industries, as they will be able to identify opportunities and sustain growth, while at the same time minimising the environmental impacts of their industry (Kesidou and Demirel, 2010).

Furthermore, there are also regulatory and voluntary pressures that are driving companies to increase green technology research and deployment. The planned implementation of the carbon tax by National Treasury is encouraging more companies to investigate green technology opportunities (CDP, 2012). Some companies, particularly the Johannesburg Stock Exchange (JSE) top 100 companies in South Africa, have already increased their focus on green technologies due to voluntary reporting requirements, such as CDP Climate Change programme (formerly known as the Carbon Disclosure Project) and the Global Reporting Initiative, which expect companies to report their emission reduction initiatives and identify their climate change risks and opportunities. By reporting through these voluntary programmes, companies begin to think beyond climate change and environmental risks to seeking opportunities (Ernst and Young, 2011; Nicholls and Moolla, 2012).

One important opportunity that drives green technology development in business is the enhancement of reputation with stakeholders. Globally, consumer demand for sustainable products is increasing and there is potential for companies to meet and increase this demand if they are more innovative and effectively market new technologies (UNEP, 2012c). There are also a number of movements driving investors and asset managers to integrate sustainability into their decision-making processes (CDP, 2012). By increasing innovation in green technologies, companies are also able to attract and retain higher quality employees. Furthermore, increased green technology adoption can enhance companies' reputation with communities and civil society by building trust, giving them credibility and can assist with achieving overall behaviour change (Luken and Rompaey, 2007).

7.4 Defining the Role of Business in Green Technologies

To understand the role that business plays in green technologies, a useful starting point is the clean technology innovation life cycle. Traditionally, innovation is driven by both technology push factors and market pull factors. Technology push factors focus on R&D of green technologies primarily through publically funded programmes. Market pull factors depend mostly on market demand and corporate investment in R&D to respond to market demand. Innovation requires a complex interaction of pull and push factors that are not necessarily linear (Grubb, 2004).

Figure 7.2 shows the stages of green technology innovation and the various influencing factors, including research institutes, the policy environment, private finance and market demand. While this life cycle is very similar to other innovation life cycles, a key difference is the need for government support in the development and diffusion of clean technologies through a range of mechanisms, for example internalising the costs of environmental externalities of carbon-intensive energy sources and products that would assist in making clean technologies more competitive in the market (OECD, 2010). The figure indicates a number of feedback loops from different stages in the innovation cycle that inform further R&D and provide knowledge-sharing from market experience (Grubb, 2004). Furthermore, for some innovations it is necessary to develop supporting technologies, institutions, as well as awareness initiatives, to ensure public acceptance and uptake.

In Chapter 2, reference was made to TRL as a prioritisation tool. The link between the TRL and the stage in the clean technology innovation cycle is noted here, with those technologies with high TRL values being close to the commercialisation stage.

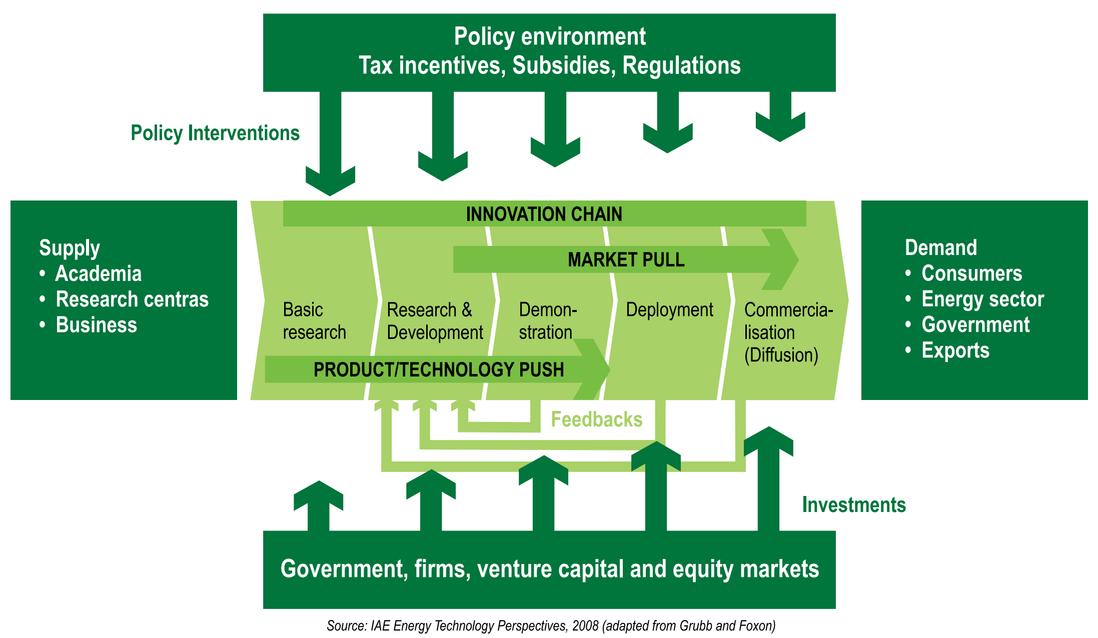


Figure 7.2: Stages in the technology innovation life cycle (IEA, 2008)

Depending on the technology type, these technology stages may vary significantly. For example, the ICT sector is characterised by high degrees of innovation, rapid technological change and is primarily funded by the private sector. The virtual nature of many ICT products, such as mobile applications and online shopping, also allows for rapid deployment and commercialisation phases. In contrast, in the power generation sector, technological change is slow and driven primarily by the public sector. Large-scale energy production requires high capital investments and long timescales, which increase the risks of such investments. A key feature of technologies that have high private sector R&D is product differentiation (e.g. smart phones), whilst efficiency and price of the same technology is the main difference between competitors in large-scale power generation technologies (Grubb, 2004).

Business consists of a range of sectors of various sizes, ranging from SMEs to large multinational corporations. Each plays different roles in green technology development and uptake, and is also confronted with different barriers and opportunities. While some companies are engaged in the creation of new technologies, most firms imitate or adapt existing production techniques to local conditions (Evenson and Westphal, 1995; UNCTAD, 1999). The various roles that the private sector plays in green technology innovation and deployment are illustrated in Figure 7.3 and are described below.

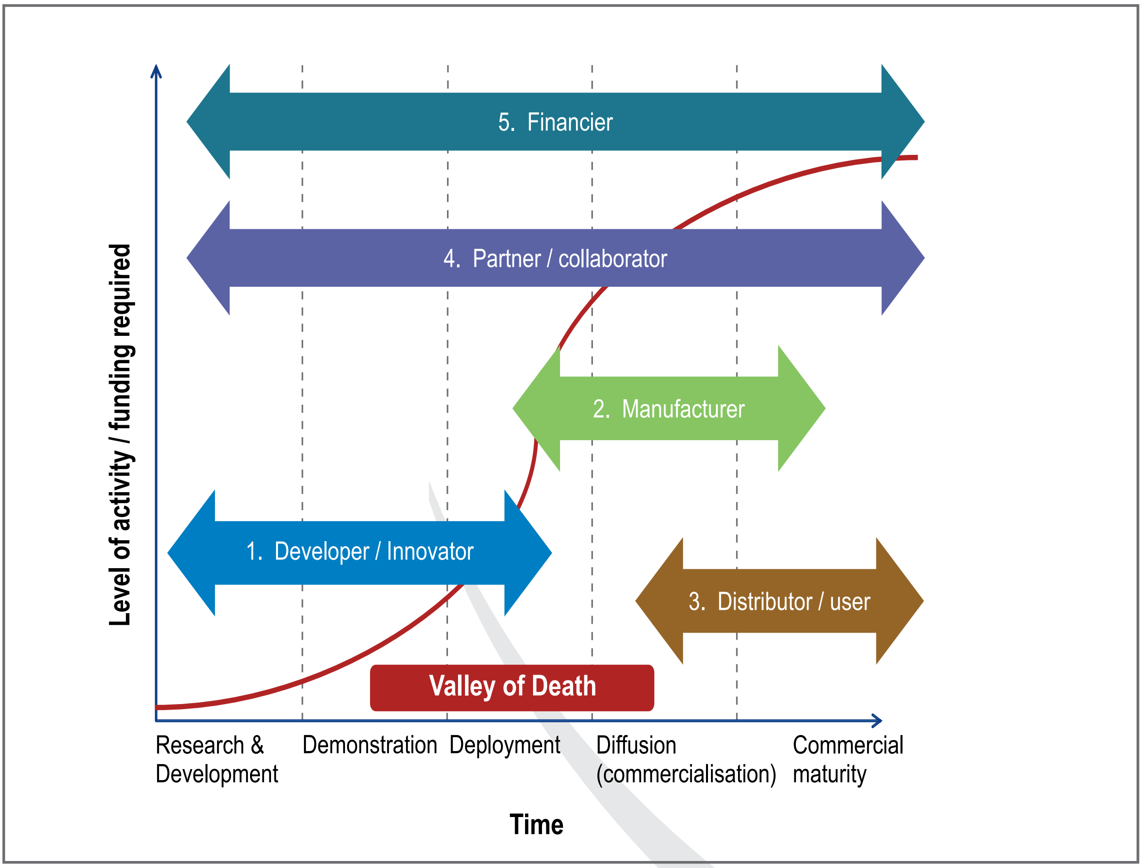


Figure 7.3: The roles of business in various stages of the technology development and deployment life cycle (adapted from Cleantech Group and WWF, 2012)

1. **Developer/innovator:** Business has long been a leader in green technology development and innovation. Business has a good ability to embrace ideas, innovate, conceptualise and develop solutions, mainly due to an awareness of market conditions and in response to demand (WBCSD, 2002). Companies that are green technology developers are commonly known as 'early adopters' and have R&D facilities within their organisations. Technology innovators are also usually responsible for the market demonstration of the technology to show potential purchasers the technology's performance and market potential. Green technology innovators in business can either be large companies that have an R&D unit or smaller technology development companies, such as engineering or information technology (IT) companies. While large companies playing in this space are able to fund their innovations, their challenge is that they require longer time frames to make decisions and are more risk averse, as opposed to smaller companies that are able to make rapid decisions and are risk takers, but are faced with the challenge of sourcing funding (Lindegaard, 2012).

2. **Manufacturer:** Once a technology has been demonstrated, established firms may adopt the technology through an agreement with the developer (e.g. by purchasing a production licence) and manufacture the technology for distribution. In some cases, companies, particularly large companies, play the roles of both innovator and manufacturer.

3. **Distributor/user:** Distributors are mainly wholesalers and retailers who sell products to consumers. As businesses procure technologies for their own use and for distribution to consumers, they have a role to play in making informed and responsible choices in the technologies they use. Distributors can potentially influence their supply chains by providing support, information and guidance to their suppliers to improve their products or by requiring that technologies meet certain standards. As technology distributors, these companies can also influence consumer demand for green technologies by introducing them to the market in ways that enhance their widespread acceptance by society and thereby increase uptake and diffusion.

   The private sector is also an important user of green technologies and has the potential to create the market demand for sustainable technologies. The user has a role to play in ensuring that products procured meet sustainability criteria, including environmental sustainability, and also in ensuring that technologies and products acquired are socially sustainable. A relevant example is that of Woolworths partnering with Imperial Logistics to improve the sustainability of their transportation chain, thereby reducing emissions and costs (NBI, 2013b).

4. **Partner/collaborator:** As a partner and collaborator, business has an important role to play across the technology development life cycle, but is also necessary from a technology transfer perspective. Businesses, academia and research institutes need to partner with each other to ensure that the R&D in this sector is market-driven and has the necessary support to ensure commercialisation of technologies (Grubb, 2004). Academia and research institutes have the research capabilities that can be lacking in companies, while companies have a better understanding of technological needs. Increased partnerships between universities, research institutions and business can increase innovation in the green technology space. More collaboration with research institutes will also assist the integration of skills needed in formal education systems and build capacity in companies to ensure that green technologies are more widely understood and implemented (KPMG, 2012) (See Box 7.1).

Box 7.1: Anglo American Platinum: driving fuel cell development in South Africa

"Collaboration with various research institutions, fuel cell companies, government and business is essential to successfully drive fuel cell technologies in South Africa" – Kleantha Pillay: Senior Manager, International Market Development, Anglo American Platinum Ltd, 2013.

Anglo American Platinum is the world's leading primary producer of platinum and accounts for about 37% of newly mined production globally (Anglo American Platinum, 2013a). With South Africa holding 75% of the world's platinum reserves, Anglo American Platinum Limited (Anglo American Platinum) believes that it is important to invest in developing sustainable markets for platinum group metals (PGMs).

A key development area for platinum lies in accelerating the use of platinum-based fuel cells for small and large-scale provision of electricity in mobile, stationary and portable applications (Anglo American Platinum, 2013b).

In order to accelerate the commercialisation of fuel cell technologies, and to create a local market for deployment and eventual assembly and manufacture of these technologies, Anglo American Platinum has well-established partnerships with a range of stakeholders, including technology developers, research institutions and government at various stages in the technology development cycle, both locally and internationally.

Research and Development: Anglo American Platinum recognised that in order to accelerate the development and deployment of fuel cell technologies, there was a need to collaborate with international developers who can provide the expertise where needed and transfer those skills to ensure the development of products for local and global use. In partnership with the DST, Anglo American Platinum has also invested in building human capacity through investing in fuel cell research as part of the HySA programme. This includes the funding of research programmes at local universities and encouraging collaboration with international institutions to encourage the transfer of skills and provide access to new methodologies and equipment. These initiatives have the benefit of ensuring technology transfer while, at the same time, building local capacity.

Together with its partners, Anglo American Platinum has developed underground fuel cell locomotive and dozer prototypes for use at its own mining operations. Surface testing to refine the design criteria are largely complete, with underground testing beginning towards the end of 2013. A large part of the technical feasibility includes the design of the hydrogen fuelling infrastructure for underground use. Extensive risk assessments form part of this feasibility phase. In parallel, the value proposition and business case is being developed, with the ultimate goal to commercialise fuel cell-powered mining equipment in South Africa.

Piloting fuel cell technologies in South Africa: Anglo American Platinum, in partnership with Thermal Coal, operates a stationary fuel cell on the thermal coal exploration site near Lephalale (Limpopo province) fuelled by coal-bed methane from the site. The project has provided valuable insights into stationary fuel cells on a coal-bed methane fuel source and its applications within the African environment and will provide learning experiences for institutions and students for the further development of this technology (PGM Development Fund, 2013).

Commercialisation: Anglo American Platinum partnered with the DST and Altergy to create Clean Energy Investments in the South African market. This company focuses on fuel cells for back-up power application in the telecommunications industry. The aim is to market, distribute and eventually manufacture fuel cell products locally for the sub-Saharan African market. This public-private partnership can potentially enable South Africa to become a world leader in fuel cell technology while ensuring local beneficiation (PGM Fund, 2013).

Business also has a collaborative role to play in partnership with government, across all spheres. Building transparent relationships with government will build trust, and facilitate knowledge-sharing and capacity building that is needed to increase the development and use of green technologies in the country (KPMG, 2012). Government can work closely with companies to identify what is needed to create enabling environments to promote green technology innovation and diffusion. Public-private partnerships can assist with increasing cleantech R&D, assist in the demonstration of new technologies and the creation of new markets (IEA, 2012a).

Business-to-business partnerships refer to the role that business has in partnering with their supply chains, competitors and service providers to share ideas and drive efficiencies through innovation along their supply chain. Companies are closely reliant on their front and back supply chains. Understanding the degree to which a company's supply chain uses resources can enable the company to establish partnerships for a creative, proactive, supply chain that can help to develop new approaches, while driving down costs and mitigating risks (SustainAbility, UNEP and UNGC, 2008).

Furthermore, companies are now beginning to work together to investigate ways in which waste outputs from one company can be used as a resource by another company (industrial ecology) (Ellen MacArthur Foundation, 2013). Internationally, companies are forming green clusters, which are a collection of related industries in the value chain. Forming green clusters helps to increase innovation through diversity, introduce new growth drivers, enhance national competitiveness and stimulate economic growth and job creation (Yoon-Jun, 2010).

Business networks, such as the Energy Efficiency Leadership Network in South Africa (NBI, 2012), also provide useful platforms for engagement, where companies from different sectors, including research institutions and government representatives, meet regularly to discuss new innovations and share ideas to improve energy efficiency at their company. Networks play an important role in increasing technology uptake and transferring technologies across different sectors.

5. **Financier:** This business role refers primarily to the private finance institutions (banks and private equity companies) that fund green technology projects. Financiers provide both development capital and procurement capital for clean technology projects. Development capital is capital that is required for R&D, production and commercialisation of a technology, while procurement capital is required for purchasing and installing green technology assets. Development capital is vital for driving innovation, improving products and increasing operational efficiencies (Accenture and Barclays, 2011). Commercial financial institutions mostly fund products that reach the commercialisation stage. Public R&D is insufficient either in quantity or in terms of its linkage to commercially viable technologies to fund technologies to the commercialisation stage (NBI, 2013a). As a result, there is a market gap in the centre stage of the technology innovation life cycle that terminates many promising new technologies in the R&D phase termed the 'technological valley of death' (Grubb, 2004; NBI, 2013a).

   Earlier sources of finance depend mainly on venture capital and private equity investment. Procurement capital ranges from small-scale individual investments to large-scale infrastructural projects like renewable energy (Accenture and Barclays, 2011). Private sector finance plays an important role in the entire green technology innovation life cycle, however, it is most common during the commercialisation and commercial maturity stages.

7.5 Opportunities, Barriers and Trade-offs in Green Technologies

7.5.1 Opportunities

The global trend towards transitioning to a low-carbon economy presents a number of opportunities for business, with the roles varying across the different sectors.

Opportunities related to green technology adaptation for business are:

- **Improved efficiencies and cost reduction:** By implementing green technologies, companies can improve production efficiencies and reduce their operating costs, such as energy and water costs and maintenance costs. Green technologies are sometimes viewed as win-win solutions as they are beneficial for the environment, while also improving productivity and economic growth. Cost savings depend on the payback period of various technologies. Many energy efficiency technologies have shorter payback periods (less than three years) and result in cost savings over the short term (CDP, 2013; UNESCAP, 2012). Table 7.1, which illustrates the payback periods of various emission reduction activities from South African CDP responders, shows that 77% of energy efficiency initiatives as a result of processes (e.g. heat recovery, refrigeration, fuel switching) have payback periods of less than three years. Large-scale technologies, such as renewable energy technologies have higher start-up costs than traditional energy technologies, however, over the long term, future savings can make green technologies a more cost-effective option (Luken and Rompaey, 2007; UNESCAP, 2012). This is also shown in Table 7.1 where 45% of low-carbon energy installations have payback periods of between one and three years in 2013, which is up from 30% in 2012 (CDP, 2013).

Table 7.1: Payback periods of South African CDP responders for emission reduction initiatives (CDP, 2013)

Emission Reduction Activity	<1 year	1-3 years	>3 years
Transportation: use	75%	0%	25%
Transportation: fleet	17%	33%	50%
Product design	50%	50%	0%
Process emissions reduction	27%	36%	36%
Low carbon energy purchase	0%	0%	100%
Low carbon energy installation	26%	30%	43%
Fugitive emissions reductions	20%	0%	80%
Energy efficiency: processes	30%	34%	37%
Energy efficiency: building services	28%	38%	34%
Energy efficiency: building fabric	18%	18%	64%
Behavioural change	79%	7%	14%

- **International trade benefits:** Developed countries, like those of the European Union, can have strict environmental requirements for products that they import. Adopting green technologies can help companies that export goods to developed countries gain a competitive advantage and an international market share, as they would meet the stringent environmental requirements imposed (Luken and Rompaey, 2007; UNESCAP, 2012).

- **Minimise risk and build resilience:** Climate change and natural disasters can disrupt or change the way business operates and result in high costs and infrastructure losses. Companies are increasingly investigating new technologies that make their company, consumers and society more resilient to shocks, disruptions, and costs of climate change impacts (PWC, 2013). By developing more resilient energy and water infrastructure, companies can minimise risks related to extreme weather events, cost increases of resources and stricter environmental regulatory pressures (PWC, 2013; UNEP, 2012c). For example, small-scale renewables such as roof-top solar PV can endure storms, floods, and other disasters with minimal or no disruption to the energy supply (PWC, 2013).

- **Product differentiation:** By investing in green technologies, companies are able to identify new market opportunities, stimulate innovation and allow companies to gain a market share through intellectual property rights (UNEP, 2012c). For example, Siemens, one of the world's largest suppliers of environmental technologies, through diversifying its portfolio to incorporate green technologies, has generated €33 billion in revenue in 2012 through its environmental portfolio, which accounts for 42% of its total business (Siemens, 2012).

- **Environmental reputation:** Increasing the implementation and distribution of green technologies can improve a company's reputation, which is important as many investors and consumers are incorporating environmental factors in their decision-making processes (Luken and Rompaey, 2007; UNESCAP, 2012).

- **Create jobs:** Increasing innovation and deployment in green technologies will create a number of jobs in existing companies and in new emerging companies. The IDC's study on Green Jobs estimated the direct job potential in South Africa as a result of green technologies to be 230 000 employment opportunities in the long term (2025), of which 130 000 jobs are associated with green energy generation, 68 000 jobs are associated with energy and resource efficiency activities and 32 000 are associated with emissions and pollution migration-related activities (Maia *et al.*, 2011).

Box 7.2: Green technology transfer

Technology transfer is one opportunity that business has of implementing green technologies, through the importation of technologies produced in developed countries. The benefits of technology transfer are that it increases diffusion of green technologies in developing countries, can potentially minimise costs of technologies by leapfrogging the fixed-line technology process and, if done correctly, can create jobs and build skills for further innovation.

Technology transfer includes "not only the purchase and acquisition of equipment but includes the transfer of skills and capacity to use, operate, maintain, as well as to understand the technology hardware so that further independent innovation is possible by recipient firms" (cited in Shashikant and Khor, 2010). The transfer of green technologies from developed to developing countries can be done in the following ways:
- Transfer from multi-national parent companies to subsidiaries.
- Through joint ventures between local and international companies.
- Trade – importers can improve their products by importing green, efficient inputs which may not be available domestically.
- Direct transfer as firms engage in the trade of knowledge through licensing agreements that typically involve the purchase of production or distribution rights and necessary know-how.

To increase the transfer of green technologies, both supply and demand factors must be considered. On the supply-side, companies and investors involved in green technology transfer seek countries with the necessary skills, infrastructure and regulations that would encourage further development. On the demand-side there must be sufficient demand to enable green technologies to be diffused effectively.

Governments in developing countries need to nurture the transfer of green technologies by building technical capacity and by creating an institutional framework that enables them to absorb, adapt and improve the transferred components and systems. An institutional framework can act as a screening process to ensure that technologies transferred are appropriate in a local context and that it meets localisation requirements (Ockwell *et al.*, 2008).

A key challenge to technology transfer is IPR. Depending on the type of IPR, such as patents and copyright protection, IPR could increase the costs of importing technologies, limit the sharing of knowledge and skills transfer and reduce growth possibilities obtained from imitation and localisation of technologies. Many proponents view green technologies as a public good that should be made freely available to developing countries. Calls have been made to the UNFCCC and trade-related aspects of intellectual property rights to use multilateral funds to buy up green technology IPR and make it freely available, however, these discussions are still in progress (Gopakumar, 2013; KPMG, 2012; Ockwell *et al.*, 2008).

While technology transfer can bring many benefits for increasing green technology diffusion, it is important to note that in some instances developed country solutions are not suitable in developing countries and developing countries play an instrumental role in creating new technologies or adapting existing technologies to meet local needs.

7.5.2 Barriers

There is a range of barriers affecting business, again varying according to sector, business size, availability of supporting infrastructure, human resource capabilities and geographic region (Park, 2005). Studies have categorised barriers differently, however. From a business perspective, a useful categorisation is in terms of the overarching macroeconomic and policy barriers that a company faces; then barriers related to a company's supply chain, including suppliers and consumers; and finally, company-specific barriers in relation to green technology uptake and diffusion. This categorisation is to provide structure to the barriers and is not intended to be deterministic. Furthermore, the number of barriers in each category is not an indicator of the relevance of particular barriers, as a single barrier may have a disproportionately high or low impact. Table 7.2 summarises the barriers that face business in green technology development and deployment.

Table 7.2: Barriers to green technology uptake in business

Category	Barrier (Luken and Rompaey, 2008; NBI, 2013a; Park, 2005; UNESCAP, 2012)
Macroeconomic/ Policy Barriers	Lack of certainty and consistency in policies in the country
	Limited incentives driving green technology uptake
	Communication challenges between government and companies
	Implementation and structural provision to support green technology development is limited
	High costs of green technology investments and uncertainty around return on investment
	Limited access to finance for green technologies in certain stages of the technology development life cycle
Value Chain Barriers	Minimal green technology supply market
	No known or cheaply available alternative chemical or raw material
	Limited customer demand for cleaner technologies
Company – Technology Interaction Barriers	Lack of commitment from top management
	Companies are structured as silos thus limiting innovation that requires alignment of business and technology functions
	Lack of information, awareness and skills within companies, especially smaller companies
	Competing business priorities such as the pressure for short-term profits

- **Macroeconomic/policy barriers**

Policy and regulatory-related barriers may result from delays in revising and developing regulatory frameworks and policies to increase investor confidence and certainty in green technology development. In addition, there are co-ordination and communication challenges between government and business. While there are some incentives to drive green technology uptake in South Africa, these are limited. According to an Ernst and Young (2011) Global Cleantech Adoption Survey, the most important role for government in supporting cleantech is to provide financial incentives and subsidies. It is important for government to simplify and streamline the regulations to improve efficiencies and increase cleantech diffusion (Maia *et al.*, 2011). These barriers primarily impact on developers and manufacturers, who are subjected to older regulations and policies that do not account for green technologies. Furthermore, policy-related barriers due to a 'misalignment between green economy vision, industrial policy and structure of the financial system', result in uncertain markets that restricts funders' ability to invest in low-carbon technologies (NBI, 2013a).

"Government needs to provide business with clear targets, rules and timelines, as well as an articulated desire to give the private sector a role and space to act in order to increase the supply and use of clean technologies" (K. Ireton, pers. comm., 29 November 2013).

To implement some green technologies requires a sub-set of other technologies, infrastructure and capabilities to allow for the technology to be implemented successfully. For example, in the case of electric vehicles, it is necessary to provide the technological infrastructure to support the charging of batteries, increase skills in manufacturing and maintaining the vehicles, and initiate a drive towards behavioural change and uptake of the new technology[10]. This is a key barrier for technology manufacturers and importers, who are reliant on certain structures, resources and other technologies to ensure the success of manufacturing a new technology.

While there are cost-saving benefits of developing and using cleantechs, for large-scale technologies these benefits have long payback periods. Traditional technologies are cheaper over the short term and generally have less operational risk and uncertainty. The high capital investment and operating costs of green technologies are major barriers to uptake (Gunningham and Sinclair, 1997; James, 2013; Park, 2005).

According to a survey by the NBI (2013) that focused on 'Enhancing private sector access to climate finance in South Africa', the process is also hindered due to a range of barriers that limits access to climate finance. Structural barriers include limited funding available for early-stage, high-risk projects that assists projects to move to commercialisation. Furthermore, mid-sized private sector project funding is limited (between R50 million and R250 million in value) because they are too large for development institutions but too small for commercial banks to pursue (NBI, 2013a). This is especially prominent in SMEs due to the absence of appropriate funding mechanisms (Gunningham and Sinclair, 1997; Park, 2005).

Project developers as well as commercial banks face skills and capacity constraints to effectively access or provide the necessary funding. In commercial banks, the

[10]http://evobsession.com/electric-car-sales-increased-228-88-2013/

decision to fund a project depends on whether the project proposal is bankable (NBI, 2013a). The NBI survey (2013) indicated that these skills are generally lacking in South African low-carbon project developers. This is also seen in the commercial banks and there is a general lack of skills to evaluate these projects. There is a need for new and innovative sources of financing that deals with unique environmental and climate change challenges (KPMG, 2012; NBI 2013).

- **Supply chain barriers**

Along the value chain, companies are also faced with a number of challenges. On the supply-side, there are a number of barriers limiting a company's access to green technologies. Suppliers may not supply new, green technologies for various reasons, such as lack of knowledge and skills required for providing these technologies. In some instances there is no known alternative chemical/material input or process technology available (Luken and Rompaey, 2007).

Furthermore, many companies are discouraged from green technology development and commericalisation due to a lack of market demand for these products. A key enabler for diffusion of green technologies is the need for market pull factors, such as customer demand (Luken and Rompaey, 2007). While consumer demand may exist in developed countries, in South Africa it is still minimal, as consumers associate these technologies and products with higher prices (CDP, 2012). Consumer demand is primarily driven by price, appeal and convenience. Depending on the green technology, the complexities and price of clean technologies drives consumers to purchase traditional technologies. For example, the extensive process of acquiring solar water heating rebates, higher short-term costs, as well as the time taken to select and install a suitable SWH, makes purchasing a traditional geyser a more convenient option (K. Ireton, pers comm., 2013; Naicker, 2010). There is a need for societal behavioural change to increase the demand for many green technologies.

- **Company-technology related barriers**

Getting buy-in and commitment from top management is a key barrier that companies need to overcome to increase the implementation of green technologies.

An important barrier to the widespread adoption of green technologies is the inaccessibility of appropriate information and expertise. A lack of awareness and expertise also limits the ability of top management to make decisions that would increase innovation and implementation of green technologies. Although there is a high potential for green technologies to improve a company's competitiveness, in many instances they lack the knowledge and skills to exploit these opportunities. This lack of knowledge increases the risks and uncertainties of adopting new technologies. SMEs, in particular, suffer from a lack of resources and expertise to devote to increase green technology uptake (Gunningham and Sinclair, 1997; Park, 2005).

Companies are also faced with competing business priorities. In most instances, activities or technologies that show short-term profitability are favoured over green technologies. Furthermore, in some instances companies are judged by markets and investors on short-term performance, which results in a reduction in long-term green investments, undermining the future competitiveness of corporations (Gunningham and Sinclair, 1997; James, 2013).

Overcoming these barriers can be complex as it requires support and collaboration of a variety of stakeholders including government, business, NGOs, research institutions and civil society.

7.5.3 Trade-offs

While green technologies provide many opportunities for business, there are a number of trade-offs that business needs to consider when developing and commercialising green technologies. Much of this chapter has focused on the role of business in the stages of technology innovation and commercialisation, however, studies have shown that there is also high mitigation and adaption potential in scaling up and adapting existing technologies. Companies need to decide whether to invest in R&D to develop their own technological solutions or whether to scale up existing technologies. The decision between technology development and/or technology deployment will determine the technology trajectory of the company. The timing of R&D cleantech investments by companies impacts on the company attaining a 'first-mover' advantage, however, this is also associated with high start-up costs (Pinkse and Kolk, 2010).

Increasing the development and deployment of green technologies in companies can potentially redefine a company as there is a shift from traditional carbon-intensive technologies to cleaner technologies (Pinkse and Kolk, 2010). This structural change in firms would require a different skills set and could potentially result in job losses of traditional industry jobs. However, this can be mitigated through reskilling and re-education programmes to ensure that these people are reabsorbed into the workforce (Maia *et al*., 2011).

The complexities and risks of partnerships is another trade-off that companies must face to increase green technology uptake. In order to find solutions for complex environmental issues it is important for companies to cooperate with others, even across sectors, to find systemic solutions. To ensure diffusion of green technologies it is important to influence the entire sociotechnical system. Single companies cannot do it alone as they depend on complementary technologies, as well as capabilities such as consumer demand for the technology and government regulations. This creates a trade-off between cooperation to achieve optimal levels and competitiveness through becoming leaders in the green technology space. The benefit of cooperation is that it allows for a sharing of risks, reduces the amount of resources required and increases levels of innovation and knowledge. On the other hand, if cooperation is with a similar company, it can hinder building capabilities and resources in the firm (Pinkse and Kolk, 2010).

7.6 Framework for Implementation

Whilst there are many barriers to green technology development and uptake in business, studies have shown that policy and technological certainty are vital for ensuring uptake in clean technologies. Such certainty increases stability in the market, can attract foreign direct investment, and through economies of scale can bring down the prices of green technologies. Figure 7.4, which was developed for this report, categorises cleantech projects according to the level of technological maturity and regulation and policy signals.

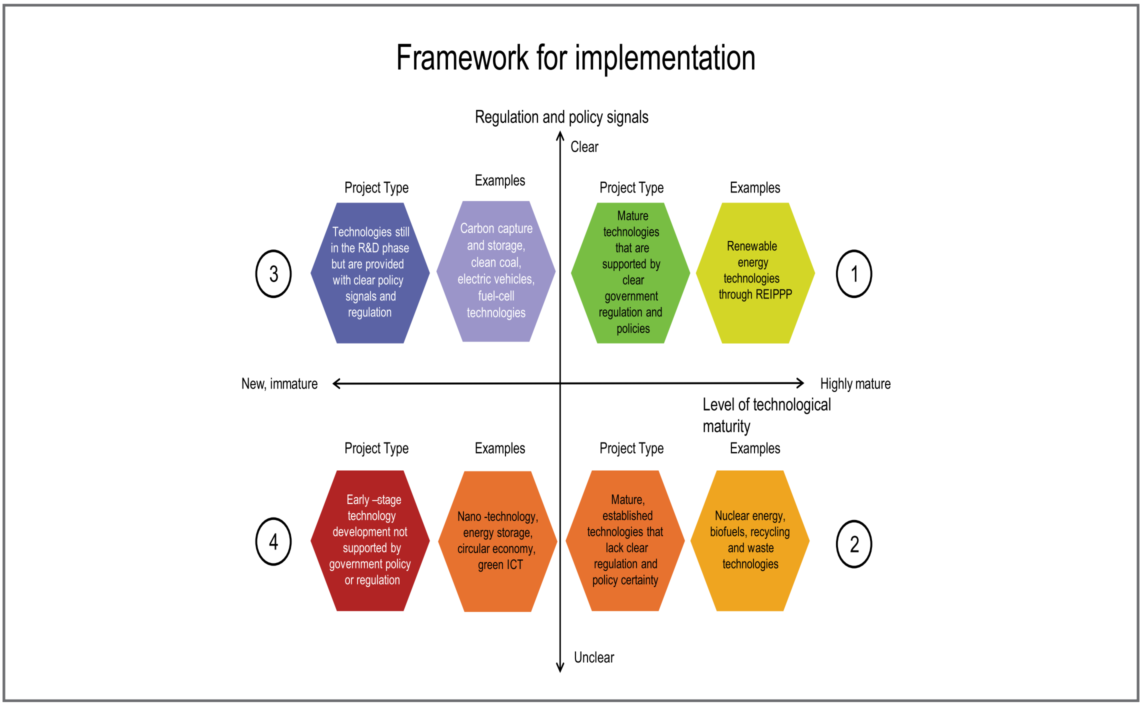


Figure 7.4: Categories of green technology projects according to level of technological maturity and policy signals

Quadrant 1 (Clear policies, mature technologies): This quadrant consists of well-established, commercialised technologies that are provided with clear policy signals, such as clear targets, strategic deployment and barrier removal policies, market incentives and market engagement programmes (Grubb, 2004). Technologies in this category are low risk and have achieved economies of scale, hence the costs of these technologies have declined.

Examples of technologies within this segment in South Africa are some renewable energy technologies through the REIPPP. The government realised that in order to diversify South Africa's energy mix and to increase renewable energy supply to the grid, the private sector's involvement was crucial. In May 2011, the DOE gazetted the Electricity Regulations on New Generation Capacity (Eskom, 2013). Government and the DoE provided clear rules and guidelines that bidders must adhere to in order to be successful. Bidders were also given a clear indication of targets and timelines were set in line with the IRP 2010 (K. Ireton, pers. comm., 2013; IPP Procurement Programme, 2012; *SAnews*, 2012). The government incorporated lessons from the previous two bidding rounds such that by the third round 93 bids were received with a collective capacity of 6 023 MW against an allocation of 1 473 MW. While only 17 bids were successful, many other applications met the criteria and there have been discussions to increase the number. This raises the number of renewable projects under or to begin construction to 64, with a collective investment value of R150 billion and an installed capacity of 3 933 MW (Creamer, 2013). Progress in this sector is significant, bringing in new funding, technologies and skills (Greve, 2013; Odendaal, 2013).

Quadrant 2 (Unclear policies, mature technologies): Well-established, mature technologies that lack clear policy signals are represented in this quadrant. These technologies are available on the global market but local policies are inconsistent and do not support the technology. This could be due to funding constraints in government, uncertainty around the technology or non-alignment of various government departments. The biofuels industry in South Africa is a good example of a mature technology that was initially in this segment, mainly due to concerns around the impacts of biofuel production on food security. Due to regulatory uncertainty many plans to build biofuel facilities, such as the Rainbow Nation Renewable Fuels soya project at Coega, were put on hold. In September 2013, the DoE provided more certainty around biofuels by stipulating that biofuel must comprise at least 5% of diesel and 2% to 10% of gasoline starting October 1, 2015. As a result, the Coega project has been brought back online and there has been a noticeable increase in the planning and development of biodiesel and bioethanol factories (*Business Report,* 2013; Payne 2013), illustrating a shift of biofuels to Quadrant 1.

Quadrant 3 (Clear policies, new technologies): This quadrant represents technologies that are still in the RD&D phase, but have received support from the public sector in terms of investment in these technologies. Whilst technologies in this sector have technology push factors such as public R&D, they lack market supply pull factors and private investment. The costs of implementing these technologies are too high and some have not sufficiently proven themselves in the market. Electric vehicles are an example of this technology in South Africa, where the government has indicated the need to promote the use of electric vehicles over the long term (NPC, 2012).

Quadrant 4 (Unclear policies, new technologies): This quadrant represents technologies that are still in the RD&D phase but lack government investment and policies to promote development in these technologies. There are high uncertainties and levels of risk in this segment and there is a need for substantial private investment, as well as government support to help promote these technologies.

Government and business need to work together to identify key green technologies that need to be pushed to Quadrant 1. Once these technologies are identified, a combination of various factors, such as increased R&D, skills development, access to finance and driving behaviour change to increase consumer demand, are needed to move technologies to Quadrant 1 in the future.

7.7 Concluding Remarks

To ensure green technology diffusion it is important to influence the entire sociotechnical system. Business has many important roles in doing this, however, business alone cannot deliver at the speed and scale of change required. For business to drive green technology innovation and diffusion successfully, business needs an enabling environment. Business needs to be encouraged to increase R&D in green technologies, and public policies, incentives, guidelines and targets linked to clear principles of sustained economic success are necessary to support green technology growth. A programme that is similar to the REIPPP initiative can be adopted to drive technological diffusion in other green technology sectors such as the water sector. Essentially, in order to grow green technologies in a country, both government and business have important roles to play. Table 7.3

highlights potential commitments to which business and government could ascribe to promote growth in green technologies.

Collaboration across companies, customers and the financial community is essential. Company collaboration is important to minimise supply chain risks, reduce the level of resources required and increase levels of innovation. Financial institutions play a dual role in the transition towards a green economy, through both investing in sustainable projects and integrating environmental, social and governance indicators into the decision-making criteria for lending, investment and insurance (UNEP, 2012). Finally, business needs to drive societal behavioural change to increase consumer demand for green technologies, by making them more attractive than traditional technologies.

Table 7.3: Commitments from business and government that would promote green technology growth in South Africa

Companies' Commitments	Government Commitments
Work with government to identify areas of green policy and regulation which can be clarified simplified while still being effective and (HM Government, 2011)	Develop a framework which simplifies policies and regulations around green technology development to promote easy uptake(HM Government, 2011)
Increase green technology R&D and commercialisation	Provide a stable commitment to policies, incentives, as well as infrastructure that supports the commercialisation of green technologies
Corporate and investment banks should work with the public sector to leverage public sector funding and develop new, innovative finance mechanisms (KPMG, 2012; NBI, 2013a)	Leverage public funding to stimulate private sector investments (Accenture and Barclays, 2011)
Identify and develop skills necessary for green technology growth within the company and through partnerships (HM Government, 2011; NBI, 2013a; Park, 2005)	Work with industry to identify and provide the right skills needed for green technology growth (HM Government, 2011; Park, 2005)
Work with research organisations, academia and government to align R&D in green technologies with business needs	Establish private-public partnerships to drive green technology R&D. Assist with translating existing innovations into a useful language for business to adopt
Promote green technology adoption with consumers and drive behavioural change	Provide nation-wide support to encourage societal behavioural change to promote green technology use
Investigate and identify green technology transfer opportunities appropriate for the South African market	Provide an institutional framework and infrastructure to ensure technology transfer incorporates localisation (Ockwell *et al.*, 2008)
Adopt knowledge sharing and open innovation approaches to facilitate ease of technology transfer (Gopakumar, 2013; KPMG, 2012; Ockwell *et al.*, 2008)	Drive a review of the intellectual property rights to more open innovation and technology sharing across industries and geographies (Gopakumar, 2013; KPMG, 2012; Ockwell *et al.*, 2008)

Companies' Commitments	Government Commitments
Engage supply chains, SMEs and other business partners to consider environmental risks, increase innovation and profitability through a broader diverse understanding of issues (Luken and Rompey, 2007)	Help small businesses to innovate and increase business understanding of environmental value and impacts. Provide support for business collaborations A potentially beneficial development is the recent announcement of the establishment of the Ministry for Small Business Development on 25 May 2014 (The Presidency, 2014). The new Ministry is to encourage small business development and to provide a platform for entrepreneurs to contribute to job creation, and economic growth and development (*SAnews*, 2014).

Chapter 8

8 SOCIAL AND BEHAVIOURAL ASPECTS OF IMPLEMENTING GREEN TECHNOLOGIES

8.1 Introduction

Many market innovators and designers will be familiar with the experience that not every successfully engineered innovation is successful in the marketplace. There is no reason to expect that green technologies should be any different. Despite the development of numerous sustainable technological innovations, a number of authors have warned about the slow adoption of these technologies by states and individuals (Hekkert *et al.*, 2008; Hensley *et al.*, 2009; Kassie *et al*., 2009). Innovative technologies often fail because they neglect to take into account the role of the user in the adoption process (Douthwaite *et al.*, 2001).

There are many factors that determine the success or failure of a specific technology, with the most common reason often being attributed (sometimes incorrectly) to cost (Lenhart *et al.*, 2003). While cost is an important component, Green (2001) suggests that the adoption and use of technology is less about cost and the technical qualities of the technology, and more about being socially bound; being determined by access to education and training, the perceived application within a society and by individual ability.

There are also many reasons why people fail to adopt a technology or discontinue its use. First, people need to know about the technology. This is largely about marketing and ensuring that the potential user population is aware of the technology. Second, people might know about the technology but see little value in making a change. Change is associated with costs, including sourcing costs (e.g. getting access to technology often has costs associated with finding suppliers); monetary costs (of buying and installing new technology); lost opportunity costs (it takes time to learn to use a new technology); and risk-taking (not all new technologies perform as advertised). Again, this is primarily about marketing to ensure that appropriate and accurate information about the benefits (and problems) reach the potential user population to help them make informed decisions. Third, people may access the technology but then discontinue use. This could be due, *inter alia*, to problems of non-intuitive design, training, operational support (e.g. a hydrogen car needs a hydrogen fuel support system), or maintenance, amongst other reasons. Finally, people could access a technology but not use it properly (e.g. use a sustainable technology in a non-sustainable way).

This chapter focuses on how people adopt and accept green technologies (i.e. the first three reasons). How people use green technologies and whether they use them in a way that supports sustainable behaviour falls beyond the scope of this report but is another important area to consider.

The first part of this chapter briefly outlines the main theories of technology adoption; *viz*. Innovation Diffusion Theory, the Technology Acceptance Model (and some of the extensions to this model), the Unified Theory of Acceptance and Use of Technology, and finally, Persuasive Design. The main focus of this first part is to emphasise the primary technology and personal variables that have been linked to the successful adoption of technology. The next section covers some of the empirical research that has applied these theories to understanding the adoption of green technologies. The final section summarises the primary variables that need to be considered when looking at consumers' adoption of green technologies.

8.2 Models of Technology Adoption

The following models and factors are described in full in Appendix 5 and outlined briefly here.

1. Innovation Diffusion Theory: The theory relies on the evolution of the mind-set of a person after initial contact with new technology through to implementation and confirmation of the new technology. A significant assumption is that the adoption of the new technology relies solely on the features or qualities of the technology, and no other external factors.
2. Technology Acceptance Models: Technology Acceptance models also rely on the features of the new technology for successful adoption but the basis of the model comprises two attitudinal components: the perception of the usefulness and the perception of the relative ease of use of the technology. Re-evaluation of the model introduced the influence of socio-economic factors including societal values, accessibility and exposure to the technology.
3. Unified Theory of Acceptance and Use of Technology (UTAUT): This theory comprises four determinants that predict behaviour of intent which in turn predict actual behaviour. However gender, age, experience and voluntariness moderate the behavioural intention.
4. Affective and Persuasive Design: These models are based on the motivation of technology design. Affective design of new technology matches the needs of the user. Persuasive technology design attempts to influence behavioural change irrespective of the needs of the user.
5. Other personal and psychological influences: Various other researchers have proposed important components to consider as determinants of technology adoption. For example, adoption of new technology was shown to be related to the purpose for which the technology was used.

8.3 Previous Technology Adoption Research addressing Green Technologies

The empirical research that has examined the adoption of green technologies is surprisingly limited, although does cover a range of products including vehicles, electricity, organic food, and IT. Janssen and Jager (2002) applied an extended version of the Innovation Diffusion Theory to try and understand why consumers would adopt green products (in general). Using simulation modelling, they were able to show that the social status of the green product and the social deliberation of the costs and benefits of the product with significant others were important determinants in the diffusion of these products. More specifically, Tanner and Kast (2003) looked at purchasing decision-making of 'green food' (i.e. domestically grown, organically grown, seasonal, not wrapped, and fair trade). They found that time expended and frequency of shop visits were the largest barriers for consumers and surprisingly, perceived costs and attitudes towards the environment were not significantly related to consumer decision-making.

Most research has been in the area of the adoption characteristics of alternative fuel vehicles, including electric vehicles and hybrid vehicles. In early work, Byrne and Polonsky (2001) looked at the factors influencing the adoption of alternative fuel vehicles. They concluded that the biggest impediments to the adoption of these types of vehicles were: a poor regulatory framework (i.e. a regulatory framework that did not categorically limit fuel emissions or provide safety standards for volatile fuels); a lack of supporting infrastructure (e.g. alternate fuel cell outlets); and technology characteristics (including price, but also perceived safety and performance). Coad *et al.* (2009), in trying to understand when users would purchase electric cars, found that important determinants were intrinsic rewards for middle-income households, women, and older people (e.g. information about the functioning of these vehicles, information about the relative benefits of fuel consumption, etc.) and extrinsic rewards for wealthier households (e.g. the introduction of incentives). Moons *et al.* (2009) found that aspects such as perceived complexity, relative advantage, compatibility, social norms, and perceived behavioural control were all important determinants in the adoption of these cars. In addition, they found that past experiences and emotional reactions to these cars were also important determinants. Hong *et al.* (2013), in trying to understand the adoption of hybrid vehicles in Malaysia, found that perceived behavioural control, relative advantage, and compatibility were the best predictors of adoption intentions. Ozaki and Sevastyanova (2011) found that the important determinants of purchase decisions were financial benefits (i.e. fuel savings and rebate incentives) and social norms established by influential peers (including celebrities). Jeon *et al.* (2012) looked specifically at the different social influences in the adoption of hybrid vehicles. They found that altruism and image were the most important social influences in China and South Korea. In a study looking at how drivers of electric vehicles overcame the perceived barrier of the range preferences (i.e. how far they would like the vehicle to travel before re-charging) for these vehicles, Franke *et al.* (2012) found that personal factors such as personality traits and coping skills were important. They suggested that the perceived barriers could be addressed through information provision, training and interface design. They also found that with experience in driving electric vehicles, range preferences became less of a barrier. Most recently, Diels *et al.* (2013) looking at green vehicles, found that only experts preferred novelty factors and that non-experts preferred design characteristics that were more typical of previous designs. This suggests that designs which stray too far from the public norms would struggle to gain traction amongst the majority of potential consumers.

Another set of studies has looked at the adoption of green electricity services. Arkesteijn and Oerlemans (2005) found that ease of switching, knowledge of the energy sources, attitudes towards the environment, and willingness to pay were all important determinants of intention to adopt green energy. Ozaki (2011) found that important determinants were social norms (i.e. the influence of significant others), perceived ease of use/adoption, and the provision of information about the innovation. Ozaki (2011) also found that even consumers who were sympathetic towards environmental issues did not necessarily intend to adopt green innovations. Unlike Ozaki (2011), in other work on the adoption of green electricity, Gerpott and Mahmudova (2010) found that a consumer's attitude towards the environment was an important determinant of adoption, together with the influence of close social contacts, although they found there were differences among high power users and moderate power users.

Lilley (2009) looked at the qualities of green technologies that would encourage their adoption. She found that important qualities were persuasive qualities (following Fogg's suggestions), perceived behavioural control, and social norms. In theoretical work, Midden *et al.* (2007) considered four roles linking persuasive technology with sustainable behaviour: 1) intermediary role (i.e. getting people to use sustainable technology); 2) amplifier role (i.e. technology amplifies the attainment of sustainability goals but also amplifies the use of resources); 3) determinant role (i.e. technology shapes behaviour by its presence/absence or affordances/constraints); and 4) promoter role (i.e. technology specifically influences behavioural choices). Thatcher's (2012) theoretical work was concerned with understanding products (i.e. technology) from an intermediary role perspective by using affective properties to influence decisions to purchase and initially engage with sustainable technologies. However, as Lilley (2009) discovered, the level of persuasive intervention that technology users are willing to accept in changing their sustainable behaviour is highly context and individually dependent.

Molla and Abareshi (2011) approached green technology adoption from a different perspective. They looked at motivational theory to suggest that eco-efficiency and eco-effectiveness motives are the best predictors of the adoption of green information technologies. It is important to note that Molla and Abareshi (2011) were looking at the motivation of entire organisations to adopt green information technologies, not individuals. Decision-making in this context might be by committee considering the benefits for the organisation and groups of people in the organisation, and not individual benefits.

8.4 Concluding Remarks

In determining which factors are of primary influence in people's adoption of green technologies, it is necessary to consider adoption as a process taking place over a period of time, with significant interactions required between the adopter and the target technology. The important variables are summarised in Table 8.1. The logical starting point is therefore the two aspects of awareness: (1) awareness that a technology exists, and (2) awareness that the specific technology may have some positive impact on socio-economic or environmental upliftment for the individual or the individual's community. At this point it is vital that there is sufficient communication by government, consumer groups, and green technology innovation companies so that people are aware of the existence of the technology, as well as the potential benefits of that technology. It is important to consider communication networks other than traditional media such as the power of early adoption by significant people (e.g. celebrities, politicians, business leaders, etc.), user-friendly websites, education at schools, and online social networking.

Next, one needs to pay close attention to the socio-economic environment in order to establish a social environment conducive to technological adoption. Technology adoption can only be considered if people actually have access to the target technology. Government can assist at this point by providing incentives such as subsidies, tax relief, and eco-labelling. Similarly, government can assist by instituting barriers to non-adoption such as taxes (e.g. carbon emissions tax for vehicles), government-regulated minimum costs, and raising disposal costs. Following Musa (2006), government also has a role to play in ensuring the right type of socio-political environment (i.e. increased employment, poverty reduction, etc.) as technology has the potential to support a positive spiral towards improvements in the socio-political environment.

The next point which one needs to consider is when the consumer actually first encounters the technology. This is influenced largely by the attitudes of the consumer which would, in turn, have been influenced by the previous two points. Attitudes refer to feelings and perceptions that one holds towards technology in general (i.e. a general disposition towards the value of technology in society in general and in one's life specifically). Drawing from the UTAUT, the 'attitudes' towards the specific technology would consist of perceived performance expectancy and perceived effort expectancy. Perceived trialability of the technology, as proposed within Innovation Diffusion Theory (Rogers, 2003), is also an important attitudinal component. These are largely qualities that must be 'built in' to the technology through a process known as User-centred Design. It is also important not to discount the contribution of persuasive and affective factors. It is evident from previous research that multiple personal factors impact on whether a person adopts a particular technology or not. It is therefore likely that there will be no single 'one-fits-all' solution. Past experience, personal preferences, personal needs, personality, social circumstances, etc. all play a role in whether a particular technology is adopted. It is therefore necessary to have diversity within green technologies to cater for this diversity in human needs and preferences.

Social pressures refer to the influences that significant others exert in order to encourage or discourage the use (misuse or disuse) of the target technology. Significant others include peers, managers, society leaders, opinion leaders, and pressure groups. The influence of the media, advertising, and other social networking processes should also not be discounted as important social pressures, depending on the social context of the technology. The influence of social pressures acts in two ways. First, social pressures act by providing an environment that either encourages or discourages the use of the technology (i.e. if you see your favourite personality using the technology there is a strong social incentive to also want to use that technology). Second, if the technology is used then social pressures act by determining how the technology is used (i.e. whether only certain functionality is adopted or whether experimentation with new functionality is tolerated). Past exposure and past experience with the target technology and with related technology are also important determinants at this point.

Personal impediments and facilitators refer primarily to demographic aspects of the individual which play a role in determining whether or not that individual is able to use the target technology or not. Situational facilitators and impediments are aspects of the particular social context and refer specifically to technological infrastructure and technical support. The socio-structural facilitators and impediments refer to legal, economic, and socio-political aspects that either impede or facilitate technology adoption. Obviously, government has a role to play in ensuring that the right supportive legal framework is in place to support the adoption of a green technology. For example, providing subsidies for solar geysers is insufficient unless government also provides incentives and training for those people installing and maintaining those geysers.

Table 8.1: Summary of important characteristics to consider

Perceived technology-related variables
Perceived performance expectancy (TAM/UTAUT)
Perceived effort expectancy (TAM/UTAUT)
Past exposure and experience (TAM2/UTAUT)
Perceived trialability (IDT)
Perceived reliability of the technology (Musa, 2006)
Perceived technical support (Musa, 2006)
Individual/psychological variables
Biographical factors (age/gender/culture/language ability)
Personality (Franke *et al.*, 2012)
Perceived user needs (Khalid, 2006)
Persuasive technology (Fogg, 2003)
Perceived behavioural control (Mathieson *et al.*, 2001)
Intrinsic motivation (Porter and Donthu, 2006)
Social/community variables
Social pressures from significant others
Legal framework including punishments and incentives for compliance
Financial incentives (relative cost, rebates, discounts, etc.)
Socio-political context (social pressure context)

Finally, while beyond the scope of this report, it is important to note that intention to use an innovation/technology is logically separated from actual use. Intention might occur as an actual behavioural action (i.e. usage), but also happens as vicarious learning (i.e. watching others use the technology) or purely as a cognitive exercise (i.e. "trialling in the mind"). One also needs to consider the usage of the technology, its continued use, and whether it is used appropriately. Usage is not a simple dichotomy (i.e. use or non-use) but also incorporates aspects such as the quantity of the usage, the extent of the usage, and the quality of the usage (e.g. does it actually bring about the social upliftment effects). These aspects will have an important impact on whether a person will continue to use the technology but also a significant impact on whether sustainability objectives are achieved.

Chapter 9

9 TOWARDS AN EVALUATION FRAMEWORK FOR THE IMPLEMENTATION OF GREEN TECHNOLOGIES IN SOUTH AFRICA

9.1 Introduction

This chapter aims to develop a framework to evaluate the implementation of green technologies in South Africa. Trends in green technology uptake are useful to inform government policy and assess policy implementation, as well as to monitor funding and the allocation of resources. Keeping track of progress in green technology uptake also assists with assessing the progress made towards fulfilling national imperatives, all of which are central to future planning. Various frameworks and approaches were considered, including the Drivers, Pressure, State and Response framework. Key considerations in selecting an appropriate framework were that the field of green technologies is broad, encompassing many sectors, and is also a newly emerging field. Indicators are beginning to be developed for some sectors, but not all. It was therefore concluded that it was preferable to commence at a higher and broader evaluation level, establishing principles and criteria, which would allow specific indicators that would measure change to be developed later.

The evaluation framework presented in this chapter is a Principles, Criteria & Indicators (PC&Is) framework adapted from the forestry sector. This particular framework is well established and utilised in sustainable forest management (SFM), both locally and abroad. The value of the PC&Is framework is that it defines particular economic, ecological and social goals related to a process or objective, and assists in measuring the extent to which these goals are achieved (Lewis *et al.*, 2002). In the context of green technology uptake in South Africa, it is important to identify the broad goals (i.e. the principles), and the management objectives (i.e. the criteria) that need to be put in place to realise these goals. Indicators then act as useful tools to evaluate the extent to which the criteria are achieved, and how this changes over time.

This chapter begins by introducing the evaluation framework, including defining key terms, and explaining how the framework could be useful in monitoring the implementation of green technologies.

9.2 Developing an Evaluation Framework: Principles, Criteria & Indicators

Developing PC&I frameworks for SFM first occurred through the Forest Principles and Chapter 11 of Agenda 21, which were adopted at the 1992 UN Conference on Environment and Development. Identifying a set of criteria and indicators to guide and evaluate the sustainable management of forests is stipulated in the Forest Principles. As a consequence of this, a number of initiatives have been established across the globe to develop appropriate forestry PC&Is for varying contexts. Some of these initiatives include the UNEP/Food and Agriculture Organisation Expert Meeting on Criteria and Indicators for Sustainable Management in Dry-zone Africa, as well as the Helsinki and Montreal Processes. These initiatives aim to develop a common framework that different countries can use to manage their forests sustainably, thereby fulfilling the commitments made at the 1992 Rio Conference. The resulting sets of PC&Is, although developed in different contexts, generally share a hierarchical structure organised around three components namely: principles, criteria and indicators (Mendoza and Prabhub, 2000) (See Box 9.1).

Box 9.1: Definitions of key terms

Principles

A principle is defined as a: "fundamental law or rule, serving as a basis for reasoning and action" (Lammerts van Bueren and Blom 1997 in Spilsbury, 2005, p.11); **a broad goal statement.**

Criteria

Criteria are defined as: "**management objectives** that are set in order to achieve the broad goals set out in the principles" (Lewis *et al.*, 2002, pp.2 – 3, emphasis added).

Indicators

Indicators are defined as: "the **tools** [or parameters] **for measuring** whether **the management objectives** set in the criteria are being achieved" (Lewis *et al.*, 2002, pp.2 – 3, emphasis added).

In South Africa, PC&I frameworks have similarly been adopted and adapted in the forestry sector. Interestingly, important pieces of legislation, such as the National Forest Act (*Act 84 of 1998*) and the National Environmental Management Act (*Act 107 of 1998*), guide and define the use of PC&Is in SFM in the country. This legislative commitment to employing PC&Is within the sector is unique to the South African context (Lewis *et al.*, 2002). In response to this legislation, the Committee on Sustainable Forest Management, and the former Department of Water Affairs and Forestry (DWAF), have designed a set of PCI&S to manage the country's forests. Through this process, national policy and international obligations were taken into account, and extensive public participation and stakeholder consultation was undertaken. The draft set of PCI&S were piloted and tested between 2003 and 2004, following which the Committee on Sustainable Forest Management recommended a set of criteria and indicators to monitor and improve the management of state-owned forests and plantations (DAFF, nd).

The value of PC&Is is that they define particular economic, ecological and social goals related to a process or objective, and they assist in measuring the extent to which these goals are achieved (Lewis *et al.*, 2002). With respect to green technology implementation, this particular framework is valuable because it calls for a clear articulation of the principles (or 'broad goal statements') of green technology implementation in the country, as well as a set of criteria (or 'management objectives'), which need to be prioritised in order to ensure that these goals are achieved. The set of indicators, in turn, provides a means by which it is possible to monitor and evaluate the fulfilment of the criteria.

The following sections outline the proposed set of PC&Is, which have been developed by drawing from a range of national policy documents and reports outlined in Chapter 3, as well as through a review of local and international literature on related indicators, the green economy and green technologies.

9.2.1 Principles of Green Technology Implementation in South Africa

There are clear advantages, economically, socially and ecologically of adopting a green growth path. There is increasing recognition, both locally and abroad, that we are facing a global ecological crisis. Natural resources are being depleted at an unsustainable rate, and the threats posed by climate change are significant. Unless a shift takes place in terms of how natural resources are managed and how the economy develops, South Africa faces a precarious future. Given the intrinsic link between economic growth and ecological integrity, a green growth path is positioned as the best alternative to decouple growth from ecological risk and degradation. Green technologies and innovation have a particularly important role to play in this transition. Not only can increased implementation of green technologies help reduce waste and pollution, but green technologies can also help improve living conditions, boost economic growth and create employment opportunities. In the South African context, it is vital that economic growth and new employment opportunities benefit the poor and marginalised in society. The South African government recognises the benefits of greening the economy and increasing the uptake of green technologies in ensuring sustainable development (UNEP, 2013).

Table 9.1 identifies six principles, reflecting the broad goals of green technology implementation in the South African context.

Table 9.1: Principles of green technology implementation in South Africa

Principles	Rationale
1. Boost economic growth	• Greening the economy offers opportunities to boost growth that is sustainable, inclusive and localised (The Presidency, 2009; EDD, 2011b; Maia *et al.*, 2011; NPC, 2011) • Green technologies have the potential to create new business opportunities, attract investment, and improve productivity, efficiency and economic competitiveness, as well as open up markets for green products and services

2. Create employment opportunities	• Green economic growth and the associated uptake of green technologies can create much needed economic opportunities (OECD, 2011b; UNEP, 2013). The South African government, in partnership with labour, business and community organisations, aims to create at least 300 000 green jobs by 2020 (EDD, 2011a)
3. Facilitate the sustainable use of natural resources	• Green technologies can facilitate the sustainable use of natural resources through improving efficiency of production processes, aiding the restoration and rehabilitation of natural habitats and systems, and through encouraging greater recycling and reuse
4. Reduce waste and pollution	• Green technologies are able to offer solutions that can help reduce waste and pollution, as well as encourage greater recycling and reuse
5. Reduce dependency on non-renewable resources	• Green technologies can help reduce dependency on limited non-renewable resources through increasing productivity and efficiency, and by providing greener, more sustainable alternatives
6. Address inequality and historical imbalances	• Green technologies can contribute to economic transformation by providing decent and sustainable employment opportunities to marginalised groups (The Presidency, 2009; EDD, 2011b; DEAT, nd) • Green technologies can be used to ensure safe and healthy living environments, as well as to improve service delivery to meet basic needs. This will help ensure progress towards promoting social justice, eradicating poverty, addressing rural underdevelopment, and improving the quality of life of all citizens

These goals embody economic, ecological and social issues that are important in South Africa, but which are also relevant globally. In order to achieve these goals, it is essential to outline a set of criteria, or management objectives. The criteria developed for this PC&Is framework are presented below.

9.2.2 Green Technology Criteria

Adherence to a set of management objectives or criteria will help ensure that green technologies realise their potential in terms of boosting economic growth, creating employment, improving environmental efficiency, and addressing social inequality. Table 9.2 outlines the five broad criteria proposed for green technology uptake and impact in South Africa.

Table 9.2: Green technology principles and their associated criteria

Principles	Criteria
1. Boost economic growth	**1. Increase financial investment in R&D to improve opportunities for the development and dissemination of green technologies** Investments should be drawn from a range of funding sectors, including government and the private sector
	2. Develop the necessary skills and capacity to foster innovation and provide the knowledge base and skills to facilitate uptake of green technologies Investment in education, skills development and training is critical Given that the transition to a green economy may result in job losses as the nature of employment changes, it is also necessary to reskill the labour force in preparation for the changes
	3. Create a business environment that is conducive to the uptake/diffusion of green technologies This may require overcoming institutional barriers (e.g. lack of state support); financial barriers (e.g. insufficient investment); socio-economic barriers (e.g. inadequate skills); and legal barriers (e.g. complicated IP processes)
2. Create employment opportunities	Meeting criteria 1, 2 and 3 will assist in increasing employment opportunities by growing the green economy
3. Facilitate the sustainable use of natural resources	**4. Ensure that the development and deployment of green technologies contribute to ecological sustainability** This can be achieved by making production and consumption processes more efficient so that green technologies use fewer resources and hence assist in better managing waste and pollution Technologies that reduce dependence on non-renewable resources can also be encouraged

4. Reduce waste and pollution	Meeting criterion 4 will help ensure that waste and pollution are reduced by growing the green economy and supporting the development of efficient, sustainable technologies
5. Reduce dependency on non-renewable resources	Meeting criterion 4 will help ensure that dependency on non-renewable resources is reduced by growing the green economy and supporting the development of efficient, sustainable technologies
6. Address inequality and historical imbalances	**5. Ensure that new green job opportunities are 'decent' and target previously disadvantaged and marginalised groups** This can be achieved by monitoring practices and procedures (e.g. ensuring that emerging green enterprises adhere to BBBEE regulations) In order for jobs to be considered decent, workers need to be provided with "adequate wages, safe working conditions, job security, reasonable career prospects and worker rights" (DEAT, nd)
	6. Ensure that green technologies are utilised to improve quality of life and basic service delivery

Together, the principles and criteria presented above provide a comprehensive picture of the goals of green technology uptake in South Africa and how these goals can be achieved. The outstanding task is the identification of a set of indicators.

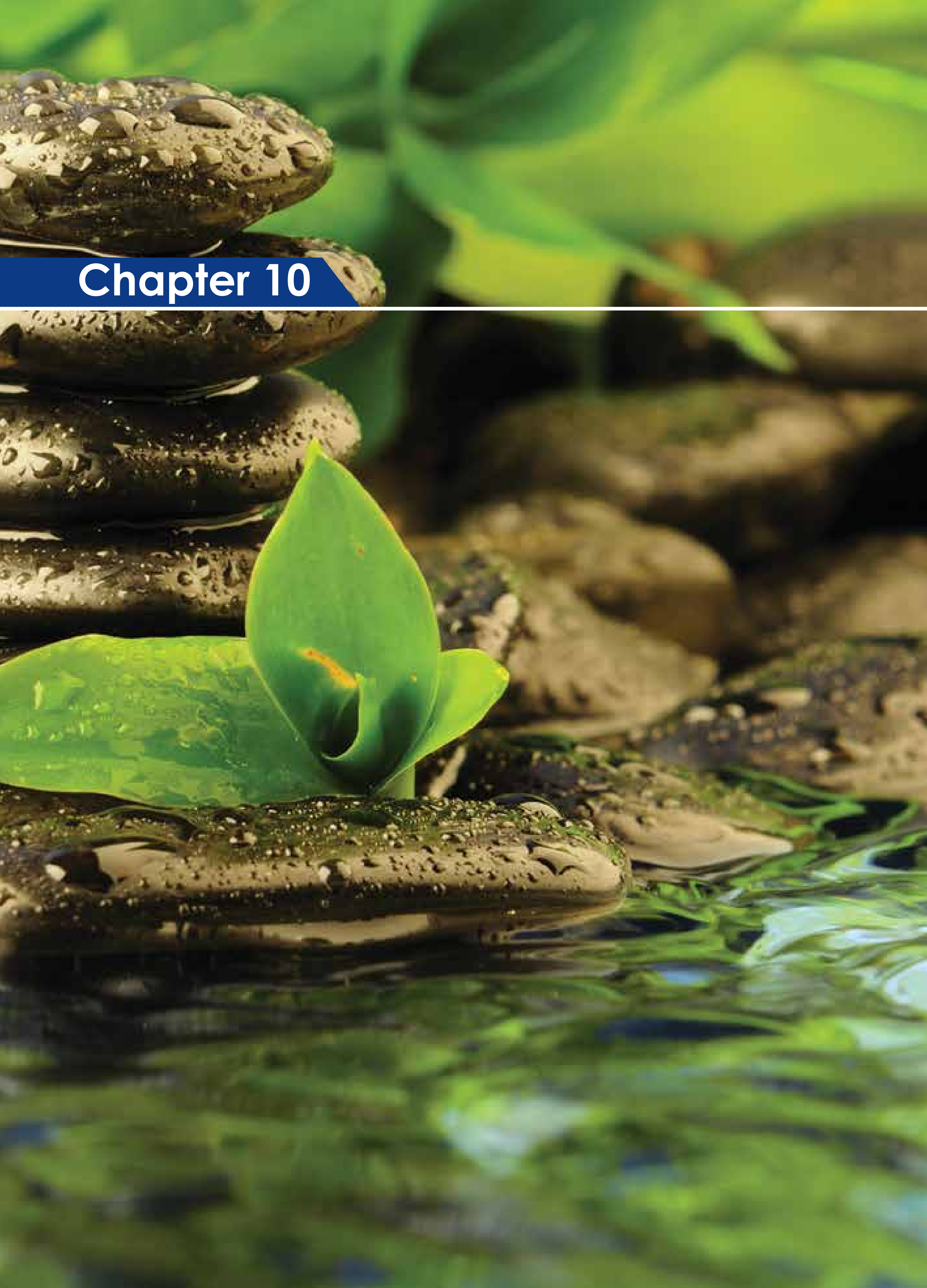
9.2.3 Developing a Set of Indicators to evaluate Green Technology Implementation

Developing a set of indicators to measure the implementation of green technologies is a complex and challenging task that is beyond the brief of this study. However, by outlining a proposed PC&Is framework based on lessons learned from the forestry sector, a foundation has been established to develop a set of robust indicators applicable to the South African context in the future. The criteria identified above lend themselves to the development of both input and output indicators. Whether it is possible to develop a generic set of indicators that would apply across all sectors or whether it would be preferable to develop sector-based indicators remains unanswered. A follow-up, consultative process should be pursued to develop a comprehensive set of indicators suited to green technology implementation.

9.3 Concluding Remarks

A PC&I framework is valuable because it is rooted in a commitment to sustainable development, it is holistic, and it allows for the definition of particular economic, ecological and social goals related to a greater uptake of green technologies, as well as assisting in measuring the extent to which these goals are achieved. The indicators, although still to be developed, provide a means by which it is possible to monitor and evaluate the fulfilment of the criteria.

Chapter 10



10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Summary of Findings

The key questions of this study were highlighted in Box 1.1 in Chapter 1. The extent to which these key questions have been addressed in this report and the major findings are summarised as follows:

Key Question 1: What are the green technologies currently available and in use in South Africa and how does South Africa compare globally in terms of the uptake of green technologies?

Chapter 5 provides an overview of the state of green technologies in energy, water, waste and sanitation in South Africa, as well as green technologies in sectors such as industry, mining, agriculture, ICT, health, transport and buildings. There was a strong emphasis on green technologies in the energy sector, as transformation in this sector is central to decoupling economic growth from negative ecological impacts and excessive resource use, and shifting to a low-carbon growth path.

Particular focus areas included energy efficient technologies, renewable energy technologies, as well as technologies aimed at reducing the environmental impacts of coal. South Africa has been very slow to introduce renewable energy technologies, but the recent improved progress in this regard was noted. Given South Africa's high dependency on coal, clean coal technologies must continue to receive attention. Energy efficient technologies received relatively early attention and major investments have been made in both the public and private sectors.

In sectors other than energy, there has been limited progress in implementing green technologies as described in detail in Chapter 5, with the general conclusion that South Africa's record in terms of the uptake of green technologies is below average. This is borne out by global ranking data. According to the Cleantech Group and WWF Global Cleantech Innovation Index 2014, South Africa is ranked 29 out of 40 countries (Cleantech Group and WWF, 2014) and is below the ranking of other BRICS countries (e.g. Brazil (25^{th}), India (21^{st}) and China (19^{th})). South Africa has below average scores for all Cleantech Innovation Index factors. However, supportive government policies produce slightly better scores in terms of cleantech-specific drivers. The top ten leading countries in terms of creativity and innovation in green technology and those that have stimulating environments for companies in the industry, either through public policy or private funding are Israel, Finland, United States, Sweden, Denmark, the UK, Canada, Switzerland, Germany and Ireland. South Africa is one of the most carbon-intensive economies globally, and national government has committed strongly to transitioning to a green economy and being a clean technology leader. However, like many developing countries, South Africa has been slow to develop and adopt green technologies despite much enabling legislation as noted in Chapter 3. The implicit assumption embedded in these policy documents is that the systems, such as financial, infrastructural, resources and skills, required to be a technology leader are in place and work efficiently in all respects, however, in many instances this is not the case.

Key Question 2: What are the political, economic, sociological, technological, legal & environmental (PESTLE) factors that influence and impact on the implementation of green technologies in the South African context?

There are many barriers that inhibit innovation and stand in the way of more effective implementation of green technologies. Those highlighted in the report (Chapter 6) include: institutional challenges, pertaining to the lack of a coherent policy framework; government bureaucracy, referring to complex and lengthy government processes, and a lack of political will, that are delaying and even preventing green investment and the implementation of green projects; skills shortages; IPR barriers; South Africa's poor track record in adopting foreign technologies; financial barriers, particularly funding during the 'valley of death' stage to ensure commercialisation and scale up of technologies; and finally, a lack of market information and an understanding of how to address human behaviour, which is addressed separately in Chapter 8.

Key Question 3: In which sectors/areas are there gaps in the availability and/or implementation of technologies and potential for future growth?

While the scope of green technologies covers a wide range of sustainable technologies in various sectors (See Chapter 1), the largest proportion of clean technology is made up of energy-related technologies, with renewable energy comprising 77% of total cleantech venture capital investment in 2010 (Cleantech Group and WWF, 2012). According to the Clean Economy, Living Planet report (WWF and Berger, 2012), the global clean energy technology market has grown 31% per annum between 2008 and 2010. The largest contributor to this sector is wind, with a 30% market share, followed by solar with 24% (the fastest growing sector) and biomass with the third largest market share of 20% (Cleantech Group and WWF, 2012).

Recently, South Africa has shown good progress in terms of the implementation of renewable energy technologies and has a solid record in terms of energy efficiency technologies. However, there is potential for growth across all other sectors if South Africa is to improve its ranking on the global scale in terms of cleantech.

Key Question 4: How best can new technologies be identified for transfer to South Africa and how should this be done to ensure that skills transfer is included?

The first part of this question relates to how best to prioritise opportunities that present themselves. In Chapter 2, various ways to prioritise green technologies were examined. Based on GHG emissions, the energy sector is clearly the prime sector for intervention and implementation of green technologies. A stakeholder-driven technology needs assessment focusing only on technologies that had not yet reached full commercialisation and where technology transfer was required, prioritised solar power and waste management under mitigation responses and the provision of water supply and sanitation under the adaptation responses (DST, 2007b). A third approach was that based on the McKinsey cost curve which takes into account cost and potential to reduce GHGs. The conclusion was that energy efficiency, the introduction of renewable energy, CCS and biofuels, offered the greatest opportunities. The technology readiness level (TRL) added a new dimension and showed that of the renewable energy technologies, such as wind and solar, wind was more mature with a TRL of 9. Solar thermal has a TRL of 6 – 8 and solar PV is some way behind with a value of 3 – 4. First generation biofuels also have a TRL of 9, with second generation biofuels scoring 5. Based on job creation potential, the natural resource management sector emerged as the most favourable point of intervention, followed by energy generation, although it was noted that energy generation created the most manufacturing jobs at 23 000.

The issue of technology transfer was addressed in Chapter 7 and the role of the private sector in green technology transfer highlighted. The transfer of technologies can be achieved through transfer from multi-national parent companies to subsidiaries; through joint ventures between local and international companies; through trade; and finally through direct transfer as firms engage in the trade of knowledge through licensing agreements. There are potentially many benefits of technology transfer as it can minimise costs and allow for leapfrogging, but it is essential that the process to diffuse technologies includes the transfer of skills and capacity development in addition to the transfer of hardware. Government policies have an important role to play in supporting the development of these skills and capacities (See recommendation 4 below) and in creating markets for technologies that are seen as priorities for South African firms to acquire and develop.

Key Question 5: Are there opportunities for new innovative green technologies that can be implemented sustainably?

Within each of the sectors addressed in Chapter 5, new innovative technologies were identified where appropriate. Five emerging technologies for the energy sector were highlighted as potential game changers for the energy sector, *viz.* grid-scale storage; digital-power conversion; compressorless air conditioning and electrochromic windows; clean coal, specifically CCS; biofuels and electrofuels (McKinsey & Co., 2012).

Key Question 6: Is there a set of indicators that can be used to measure successful implementation of green technologies?

Developing a set of indicators to measure the implementation of green technologies is a complex and challenging task. The approach adopted in this study was to establish a foundation based on the PC&Is framework, from which a set of robust input and output indicators can be developed through a consultative process. Six principles, reflecting the broad goals of green technology implementation in the South African context were identified as: boosting economic growth; creating employment opportunities; facilitating the sustainable use of natural resources;

reducing waste and pollution; reducing dependency on non-renewable resources; and addressing inequality and historical imbalances. In order to ensure that these goals are achieved, a set of criteria or management principles is identified. They are: increasing financial investment in R&D to improve opportunities for the development and dissemination of green technologies; developing the necessary skills and capacity to foster innovation and provide the knowledge base and skills to facilitate uptake of green technologies; creating a business environment that is conducive to the uptake/diffusion of green technologies; ensuring that the development and deployment of green technologies contributes to ecological sustainability; ensuring that new green job opportunities are 'decent' and target previously disadvantaged and marginalised groups; and ensuring that green technologies are utilised to improve quality of life and basic service delivery. The set of indicators, which is to be developed in a subsequent follow-up study will provide a means by which it is possible to monitor and evaluate the fulfilment of the criteria.

Key Question 7: What is needed to promote and increase the use and development of local green technologies in South Africa?

The barriers that stand in the way of uptake and development of green technologies were highlighted in Chapter 6. Overcoming these barriers requires interventions that support green transition. Various categories of instruments that could assist in the development and implementation of green technologies were considered. These included: regulatory instruments, with South Africa having an abundance of relevant policies and an enabling policy environment; economic instruments, with South Africa having a range of financial instruments such as environmental taxes, incentives and subsidies to support the growth of green enterprises; research and education instruments, which were recognised as critical to successful implementation of green technologies but acknowledging that there is a skills development lag; cooperation instruments, such as interventions that support technology transfer and voluntary agreements, with the former not having demonstrated great success to date in South Africa (e.g. CDM) and the latter having had some measure of success; and finally, information instruments, aimed at plugging the information gaps and of which many recent successful examples were given.

In addition, perspectives from the business sector were considered. Relevant factors were costs, enhancement of reputation with stakeholders, as well as regulatory and other voluntary pressures. The importance of public-private partnerships in driving green technology uptake was emphasised.

Key Question 8: What recommendations are there for policies that would assist in promoting efficient and sustainable green technologies in South Africa?

South Africa is regarded as having a favourable policy environment when it comes to green technologies. A chronological account of relevant national policies was given in Chapter 3. There are a large number of overarching and sector-based policies that refer either directly or indirectly to green technologies. The challenge was rather one of policy certainty and policy alignment and this will be taken up as one of the key recommendations. It was also noted that while favourable policies are a necessary driver for success in green technology development and implementation, they are not a sufficient condition. Green technology programmes require a balanced mix of technical, financial and legal professional service providers, innovative funding and interdepartmental leadership, and project championship to be successful. The need for this balance is very relevant for the South African situation, where there tends to be an over-emphasis on creating a favourable policy environment, with some neglect of other important factors.

10.2 Recommendations

Based on the key findings above, a consolidated set of recommendations aimed at promoting the implementation and development of green technologies in South Africa is provided.

1. Policy Certainty and Policy Coherence

Effective government policy, including both policy certainty and policy coherence, is a critical enabling factor for the successful implementation of green technologies. Lack of clarity in policy direction or shifts in government thinking can inhibit progress. An example is the shift in planned implementation date of future nuclear build from that contained in the IRP 2010 to the latest date provided in the IRP Update published in 2013 (DoE, 2013b); the implementation of further nuclear energy is delayed until 2025 or even 2035, based primarily on reduced demand for electricity. Given the enormous investments required in the nuclear energy industry, both in terms of infrastructure and human capital, policy shifts even in the form of delayed implementation pose risks for the nuclear industry.

Policy coherence is equally important. South Africa has a plethora of pertinent policies applicable to green technologies, particularly in the energy sector, and indeed one may argue that South Africa is policy-saturated. Clear targets and alignment in policies between different government departments are imperative. Lack of policy co-ordination between government departments or between departments and agencies hinders implementation. Again, an example from the energy sector relating to the recent confusion over REFIT and REBID initiatives is relevant. In some sectors, for example the waste sector, the lack of enabling policy has been highlighted as a barrier.

While policy certainty and policy coherence are critical elements of successful policies, it is important to ensure that there are mechanisms in place for a regular, systematic and transparent review of the effectiveness of policies. This is an oft neglected aspect that is incorporated into this policy-linked recommendation, in view of the critical role of policy as an enabler for green technology uptake in South Africa.

Recommendation:

Ensure that policies play an enabling role by: setting clear targets and including mechanisms to assist in meeting those targets; instilling certainty in the market; and, ensuring that there is policy co-ordination between different government departments. Make provision for a regular review of the effectiveness of green technologies policies to allow for learning to be incorporated.

2. Implementer and Developer Roles

South Africa's role in green technologies should be as both implementer and developer. With regard to the former, technology transfer can greatly facilitate access to and diffusion of green technologies. It is important that the green technologies acquired through technology transfer link to the local context and align with South Africa's development needs and green growth strategy. It has been noted in the report that technology transfer is more than just the transfer of hardware; it should also include knowledge transfer and innovation capacity. Local manufacturing of imported technologies should be encouraged. South Africa, unlike China and India, has been relatively unsuccessful in terms of attracting foreign direct investment, except for the motor vehicle industry. However, foreign direct investment alone does not lead automatically to the development of technological capabilities. An important lesson from China and India is that emerging economies also need to invest in these capabilities through R&D and skills development in the tertiary education sector and the broader national system of innovation. Skills are needed at various levels. At the entry level, skills are needed to operate and maintain technologies effectively. In addition, skills are needed to improve and adapt technologies for local needs, and most importantly, to develop innovation capabilities.

While the implementer role is critical, the developer role should be the ultimate goal, but it should be pursued strategically. Priorities need to be set and niche areas identified. Successful exploitation of the niche target areas could create growth potential for export into Africa.

Recommendation:

Prioritise niche areas for local development of green technologies based on existing innovation capacity and encourage transfer of green technologies that have a good socio-technical fit with the local context. It makes sense to prioritise and maximise synergies with current industrial and other capabilities in South Africa, but there is also a need to think about and develop capabilities in new niche areas.

3. Creation of an 'Entrepreneurial State'

There have been many references to barriers to green technology implementation that have their root in government bureaucracy; such as lengthy and cumbersome application processes, the lack of skills to process applications, and involvement of multiple agencies. There is a need for government to unlock the barriers and provide an enabling environment for innovation to flourish. An interesting argument is that presented by Mazzucato (2013) in her book *The Entrepreneurial State*, in which she argues that the role of government should go beyond that of an enabler, but should actively shape the market. She cites numerous examples of innovations that can be traced back to sound investments in R&D and education. There are some unique elements of green technologies that distinguish them from other technologies and therefore may necessitate special consideration. For example, benefits derived from green technologies are a public good and are not market driven. Furthermore, green technologies are often at the early technology development stage and may require further testing in new environmental, social and economic circumstances, leading to higher costs. Hence they may require greater policy intervention to facilitate transfer and uptake (*African Development Report*, 2012b).

Recommendation:

Government should consider itself as more than an enabler of green technologies but should actively shape the market through sound investments in R&D,education & training, and through the implementation of market incentives.

4. Skills Transfer and Innovation Capacity

Human capital development is an essential component of successful implementation and development of green technologies. It is far broader than just up-skilling or retooling a workforce or ensuring that technology transfer explicitly includes transfer of skills and skills development. It requires a strategy that recognises that a robust NSI is a prerequisite for effective implementation of green technologies. One of the foremost reasons for South Africa's failure to take full advantage of CDM opportunities, particularly when compared with other BRICS countries, can be attributed to shortcomings of the NSI. Investment in the NSI is pivotal to effective green technology uptake.

Recommendation:

Government should focus on strengthening the NSI, ensuring interconnectedness between role players and skills development at tertiary level.

5. Focus on the Market

Since the success of a green technology is predicated on widespread diffusion through society, it is important to take the end-user into consideration. End-users will only utilise green technologies that add some perceived value to their lives. Over and above financial benefits to the user, perceived value can be achieved either by user-centred design (where the design qualities of the green technology are matched with the needs of the end-user; i.e. perceived usefulness, perceived ease of use, social pressure, etc.) or through persuasive design (where the design qualities of the green technology actively encourage adoption or a change towards sustainable behaviour). Understanding the market and how human behaviour influences uptake of green technologies is critical to success. A communication strategy to promote uptake of green technologies is an essential consideration. It must be borne in mind that green technologies are a public good and may require a specially tailored strategy to encourage uptake. Furthermore, a critical success factor of green technology implementation in both Germany and South Korea was a focus on the export market. In the case of South Africa, there are opportunities to develop and disseminate green technologies for use in the Southern African Development Community (SADC) region and Africa as a whole and should be actively encouraged.

Recommendation:

Ensure that market demand is not neglected in favour of a focus on the supply-side of green technologies. There is a need for a targeted communication strategy to promote uptake of green technologies by the public and a need to plan for the export market, particularly within Africa.

6. Alignment with South Africa's Development Needs

Successful implementation and uptake of green technologies require alignment with South Africa's green growth strategy and development needs, particularly those enunciated in the NDP. Job creation, poverty alleviation and overcoming equity imbalances are critical factors that should inform investment strategies and areas of focus. They are key factors underpinning the monitoring and evaluation (M&E) framework developed in this study and serve to give direction and focus to decision-making when faced with an overwhelming number of opportunities relating to green technology implementation. Technology transfer can greatly facilitate access to green technologies but it is not about developing a shopping list of green technologies that can be imported. Alignment is critical.

Notwithstanding the points made in the previous paragraph, the NDP should not be limiting. In other words, private sector investment or consumer-driven investment should be allowed to flourish. Similarly, investments in green technologies that present opportunities for export to SADC countries or the rest of Africa, should be encouraged.

Recommendation:

South Africa's development needs, particularly job creation, poverty alleviation and the need to overcome equity imbalances, should inform and direct but not prescribe green technology investment strategies.

7. Development of Indicators

The foundation for the development of a set of indicators based on the PC&Is framework has been laid. Goals or principles, as well as management criteria, have been identified, and it is important that they constitute the M&E framework and that they are used to evaluate and prioritise green technology investment decisions. A consultative process to develop the M&E framework further and identify a set of appropriate indicators to measure green technology uptake is recommended.

Recommendation:

Initiate a follow-up study to identify a set of indicators for the M&E framework for green technology uptake in South Africa.

8. Green Technology Hubs

Special provision should be made for the establishment of green technology hubs in urban municipalities or metropolitan areas. Municipalities could consider the creation of such hubs that could be considered for tax incentives; that could form close links with a tertiary institution; and importantly, would provide a safe zone for innovation and entrepreneurship to flourish.

Recommendation:

Municipalities should consider the establishment of green technology hubs to foster development of green technologies.

9. Systematic Evaluations of Failed or Discontinued Projects

Many green technologies are at an early development stage and may be high-risk ventures. Failures should not be feared but should be embraced as learning experiences. In this respect there should be transparent and systematic evaluations of failed or discontinued projects (e.g. Joule electric vehicle) with full disclosure of the lessons learned. Only when there is a mind shift from one of secrecy and embarrassment to one of openness and willingness to learn from failures, can meaningful progress be made.

Recommendation

There should be systematic reviews of projects, particularly failed or discontinued projects, so that learning can be enhanced.

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Appendices

Appendix 1: Biographies of Panel Members

Eugene Cloete (Chair)

Professor Eugene Cloete is Vice-Rector: Research and Innovation and the former Dean of the Faculty of Natural Science, Stellenbosch University, South Africa. Prior to this, he was Head of the Department of Microbiology & Plant Pathology at the University of Pretoria until 2008 and was the Chairperson of the School of Biological Sciences. He is also the chairman of the International Water Association (IWA) South African National Committee and immediate past Vice-president of IWA International. Currently he is leading a New Partnership for Africa's Development (NEPAD) water initiative involving a number of South African and Southern African Development Community universities. In 2005, he was appointed as the Chairman of the IWA Strategic Council for three years. Cloete is the inventor of nine patents of which four are international. In 2005, he received a Technology and Human Resources for Industry Programme Excellence award for one of these patents pertaining to Biofilm monitoring as a technology benefiting a small, medium and micro enterprise during 2004. His own research has led to 120 publications and four books. His contributions have been acknowledged by numerous significant awards from a variety of different organisations. He holds a Masters degree from the University of the Free State and a doctoral degree from the University of Pretoria.

Chris Buckley

Professor Chris Buckley is a Chemical Engineer and heads the Pollution Research Group at the University of KwaZulu-Natal, Durban, South Africa. He has undertaken contract research into urban and industrial water management with the group since 1970. The primary funding is from the South African Water Research Commission, eThekwini Municipality (Durban), Eskom (power utility), Sasol (petrochemicals) and Umgeni Water (bulk water). By providing scientific support to the water and sanitation division of eThekwini Municipality, the research is grounded in the realities of service delivery to the unserved. Buckley coordinates the research and development for Borda (German NGO) which provides basic needs services to poor people in Asia and Africa. The group has participated in a number of European Union research projects and with a range of international universities.

Linda Godfrey

Dr Linda Godfrey is a Principal Scientist with the Council for Scientific and Industrial Research's (CSIR) operating unit Natural Resources and the Environment. Her research interests include the role of waste information as policy and behaviour-change instrument; the role of the waste sector in transitioning South Africa to a green economy; the economic, governance, social, behavioural and innovation aspects of integrated waste management. Godfrey has provided strategic input into a number of waste and green economy initiatives for the EU, DST, DEAT; Development Bank of South Africa; Institute of Waste Management and several local universities. She is currently working with DST to establish a strategic ten-year Waste Research and Development, and Innovation Roadmap for South Africa. She acted as co-editor of the recently drafted Joint European and African Research and Innovation Agenda on Waste Management (*Waste as a Resource: Recycling & Recovery of Raw Materials*, 2014-2020). She holds a doctoral degree in Engineering from the University of KwaZulu-Natal and is registered with the South African Council for Natural Scientific Professions as a Natural Scientist. Godfrey has published extensively in the field of waste management and provides review to both local and international scientific publications on the topic.

Diane Hildebrandt

Professor Diane Hildebrandt is the Co-director for the research unit Material and Process Synthesis at Unisa. She has authored two books, over 100 scientific papers, including an invited paper in *Science*, and has supervised over 80 postgraduate students. In 2009, she was the Winner of the Distinguished Woman Scientist Award of DST and was also Winner of the Continental African Union Scientific Awards for the category Basic Science, Technology and Innovation. She was awarded the ASSAf Science-for-Society Gold Medal in 2010. Her research area is the design of energy efficient processes and equipment, with the view to reducing carbon dioxide emissions from chemical processes. Some of these ideas have successfully been implemented in the Golden Nest Fischer-Tropsch pilot plant in Baoji, China and the LincFischer-Tropsch plant in Chinchilla in Australia.

Makhapa Makhafola

Dr Makhapa Makhafola is General Manager: Research & Development at Mintek. Makhafola, an analytical chemist who trained at the University of Manchester, England and the University of Pretoria was Director: Quality Promotion and Assurance at the University of KwaZulu-Natal. He held a similar position at the University of Venda for Science and Technology, where he also lectured. As part of his postdoctoral studies, he was responsible for developing a technique called mono-disperse dried macro-particulate injector as a sample introduction for inductively coupled plasma mass spectrometry an instrument used for metal analysis from samples originating from various industries, such as mining and food. Apart from quality management, his strategic management interests include change and people management, policy development and analysis, strategic planning, and survey and evaluation research techniques.

Anastassios Pouris

Professor Anastassios Pouris obtained his Masters degrees in Management Engineering from the Aristotelian University of Thessaloniki, Greece and Applied Economics from the University of Surrey, England. He received his doctoral degree from the University of Cape Town in energy policy-related issues. He received his executive education at the JF Kennedy School of Government of Harvard University, USA and the International Institute of Management Development, Switzerland. Pouris' research focus is the management and evaluation of science, energy economics and performance; technology and innovation systems and the transfer and adoption of best practice in the South African reality. He has undertaken research for UNESCO, NEPAD, WIPO, NRF and a number of government departments in the country.

He is member of ASSAf and of the Research, Innovation Strategy Group of Higher Education South Africa. Pouris has testified in a number of Parliamentary committees. He has published extensively.

Emile van Zyl

Professor Emile van Zyl is the Senior Chair of Energy Research in Biofuels and other alternative clean fuels at Stellenbosch University and he is also a Professor at the Department of Microbiology. Van Zyl's laboratory is well established in the microbiology and biochemistry of plant degrading enzymes and he has gained international recognition as research leader in the development of recombinant yeast for biofuel production from total plant biomass. In his capacity as Chair, he is steering a large research programme at Stellenbosch University towards the development of advanced second generation technologies for the conversion of total plant biomass to biofuels. Van Zyl's group has published more than 108 papers and has more than 20 international patents on xylose and cellulose fermentation. They have also conducted research for Mascoma Corporation in New Hampshire, USA, listed for three years in a row amongst the top 20 biofuel companies on the Biofuels Digest 2008 – 2010 listing.

Jim Watson

Professor Jim Watson is Research Director of the UK Energy Research Centre and a Professor of Energy Policy at the University of Sussex. He was Director of the Sussex Energy Group at Sussex from December 2008 to January 2013. He has a first degree in engineering from the Imperial College London and a doctoral degree in science and technology policy from Sussex. He has 20 years' research experience on climate change, energy and innovation policy. His recent outputs include a co-edited book: *New Challenges in Energy Security: The UK in a Multipolar World* (Palgrave, 2013). He frequently advises UK government departments and other organisations. He was an advisor to the government office for science for a foresight project on energy (2007 – 2008), and has been a Specialist Adviser with the House of Commons Committees on Environment, Food and Rural Affairs (2006 – 2009) and Energy and Climate Change (2010 – 2011). He has extensive international experience, including ten years of working on energy scenarios and energy innovation policies in China and India. In 2008, he spent three months as a Visiting Scholar at the Kennedy School of Government, Harvard University. He a council member of the British Institute for Energy Economics, and was Chair in 2011. He is also a member of the Department of Energy and Climate Change and the Department for Environment, Food, and Rural Affairs' social science expert panel.

Appendix 2: Biographies of Reviewers

John Marriott

John Marriott joined the World gas-to-liquids (GTL) Advisory Board in January 2004, following his retirement as Managing Director of Sasol Technologies Limited of South Africa. Marriott graduated with a degree in Chemical Engineering from the University of Cape Town in 1963. After graduation, he was employed by Sasol Limited in various technical positions. Notably he was responsible for the process design of the Gas Production units of the Sasol Two Plant during the design phases of this project from 1975 to 1979. During the Sasol Three project, which was implemented between 1979 and 1983, he was Manager of Process Design. As Manager of the Process Department of Sasol Secunda from 1979 to 1982 he was responsible for technical service during the commissioning of the two giant projects. In 1982, he was in charge of process design activities for Sasol in Rosebank and was appointed as General Manager of Sasol Limited in 1993. The overall process concept of the Mossgas fuels from natural gas, as well as the detailed process design of the licensed Sasol units were developed under his leadership. Subsequently, he was responsible for Corporate Research and Development and for technology, chemical engineering designs and for the development of new projects for the Sasol Group. During the late 1990s, he was responsible for the team updating Sasol's Fischer-Tropsch technology and positioning Sasol for a leadership role in the global gas-to-liquids business. He served as President of the South African Institute of Chemical Engineers during 1990 and 1991. He was Chairman of the National Science & Technology Forum in 2003.

Gustaf Olsson

Professor Gustaf Olsson is Professor in Industrial Automation and Professor Emeritus at Lund University, Sweden since 2006. He has devoted his research to control and automation in water systems, electrical power and process industries. From 2006 to 2008, he was part-time Professor in Electrical Power Systems at Chalmers University of Technology, Sweden. Every year since 2006 he has been Visiting Professor at the Technical University of Malaysia and at Tsinghua University in Beijing, China. He is an Honorary Visiting Professor at the Exeter University in the UK. Olsson has served in various positions within the International Water Association (IWA). Between 2005 and 2010 he was the editor-in-chief of the journals *Water Science and Technology*, and *Water Science and Technology/Water Supply*. From 2007 to 2010, he was a member of the IWA Board of Directors. He has mentored 23 PhDs and several hundred MSc students. He has received the Lund University pedagogical award for "distinguished achievements in the education". Lund University engineering students voted him 'teacher of the year'. In 2010, he received the IWA Publication Award. He has spent extended periods as a Guest Professor and Visiting Researcher at universities and companies in the USA, Australia, Japan, Malaysia, and China and has been invited as a guest lecturer to 19 countries outside Sweden. He has authored eight books – some of them published in English, Russian, German and Chinese – and more than 140 scientific publications.

Appendix 3: International Case Studies in Detail

1. Germany as a Case Study of Green Growth

Germany is the third largest economy in the OECD, and is considered by many as an international example in the transition towards a green growth model (OECD, 2012b). A key dimension to the transformation of the economy is the provision of sustainable long-term solutions to pressing international challenges, such as climate change, environmental degradation and resource scarcity, through the promotion of environmental technologies and increased resource efficiency (BMU, 2012). Furthermore, the promotion of green technologies is seen as a gateway for economic growth and employment creation (Iwulska, 2012). The commitment to green growth is reflected in German environmental policies and the increasingly challenging targets for emissions that have been introduced by the German government since the late 1980s.

The transformation of the energy sector is centrally important in Germany's green growth strategy. This is driven by the need for climate change mitigation and increased energy security (Schreurs, 2012). A second underlying reason for this transformation is the need to modernise the economy and counteract the decline of traditional sources of economic growth, such as the coal industry. Due to high levels of pollution, widespread environmental concerns and high extraction costs, the coal industry has experienced a decline, which led to job losses and economic stagnation in certain rural areas. This decline is also due to the discontinuation of public subsidies following an intervention by the European Commission. In this context, a transition towards a new economic model is crucial in order to address 'de-growth' in the traditional economic sectors (Laird and Steffes, 2009).

The loss of public confidence in the nuclear industry has also been a driving force behind the development of renewable energy sources (Jacobsson and Lauber, 2006). While government support for nuclear power has fluctuated over the last two decades, public opposition rose rapidly following the 2011 Fukushima accident, resulting in a decision for a complete nuclear phase-out by 2022. The main concerns were related to plant safety and nuclear waste storage and transport. It is clear that the planned nuclear phase-out might cause a capacity risk. To address this, alternative energy sources, as well as increased storage, need to be developed and introduced to the supply mix (Schreurs, 2012).

Finally, a relatively unique aspect of the wide diffusion of green technologies in Germany and the opposition to nuclear power is the influence of the national green movement and the rise of green politics. Since the early 1970s, environmental awareness has been prevalent among the German public and is now considered mainstream (Engels *et al.*, 2013). As a precursor to the environmental movement, citizens' initiatives groups were formed in the late 1960s to address local environmental problems. The groups were also seen as an exercise in participatory democracy and a response to frustration over limited representation in the Bundestag (Klimke and Scharloth, 2008).

Increased government support for nuclear power following the 1973 oil crisis provided a focal point for citizens' groups, which grew in popularity and were eventually organised under the umbrella of the Federal Alliance of Citizens' Initiatives for Environmental Protection. The strong anti-nuclear movement partly stemmed from the student movement of the late 1960s, as it combined environmental concerns with political protests against large corporations and the federal government (Goodbody, 2002). The movement later broadened its agenda to include disarmament, feminist issues and overall social equality, leading to the creation of a distinct counter-culture amongst the German public (Dryzek *et al.*, 2003). Its increased popularity culminated in the formation of the Green Party in 1980, which entered the Bundestag in 1983. It is worth noting that parliamentary participation brought significant conflict among Party factions, since it was seen as undermining the principle of direct participatory democracy. The more pragmatic wing of the Party (the Realos) prevailed in the early 1990s, resulting in the formation of a comparatively moderate party agenda. The success of the Green-SPD coalition in the 1998 elections signalled the first time the Party would have direct influence over environmental and energy policy (Dryzek *et al.*, 2003).

1.1 Six Green Technology 'Lead Markets'

As noted above, a key driver for the shift towards a climate-friendly economy is Germany's aim to become a market leader in environmental technology exports. In the wake of the global financial crisis, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Ministry of Education and Research launched the Environmental Technologies Masterplan that outlines ways in which policy can assist green technology exports. The focus is on water efficiency, natural resources and climate change mitigation. The directions given in the masterplan address the areas of R&D funding, training for skills development, the dissemination of new technologies and support towards green innovation small and medium enterprises (SMEs) (BMBF, 2008).

To assist market development for environmental technologies the following six 'lead markets' have been identified by the German Environment Ministry, the BMU (BMU, 2012):

1. Power generation & storage: The decarbonisation of energy generation is a major aspect of the German green growth vision. Key market development areas include the development and further expansion of renewable energy technologies and the use of energy storage technologies, which could be a prerequisite for a larger share of renewables in the energy mix.
2. Energy efficiency: Increasing energy productivity is considered crucial for Germany to achieve its ambitious climate targets. Four potential market areas for energy efficient technologies have been identified – industrial energy efficient production processes and cross-application technologies, energy efficient buildings and energy efficient appliances for personal use.
3. Material efficiency: The German government acknowledges that future economic growth should be decoupled from resource consumption.

Resource and material efficiency are the main issues targeted by environmental technologies, i.e. efficiency in raw materials extraction and processing.

4. Sustainable mobility: The transport sector in Germany is responsible for a third of the national energy consumption and approximately a fifth of carbon emissions and is therefore seen as one of the main sectors that need to be transformed. Green technologies in this area target increased personal transport efficiency, alternative fuels, alternative drive technologies, traffic management and transport infrastructure.
5. Waste management and recycling: The Closed Substance Cycle Act passed by the *Bundestag*, the national parliament of Germany, in 2011 rules that by 2020, 65% of urban waste and 70% of construction waste will be recycled. The waste full-cycle concept of converting all waste to reusable resources is reflected in waste management technologies that address waste collection, transportation, separation and recycling.
6. Sustainable water management: The treatment of drinking water and the disposal of waste water are seen as key challenges for Germany, partly due to the high energy requirement associated with these processes. Priority technologies in this area cover the complete water cycle, from water production and treatment to efficient use and waste water disposal.

1.2 Policy Instruments for Green Growth

A combination of market-based incentives and regulatory policy instruments has been introduced in order to enable the transition towards a greener economy in Germany. Policies have been regularly re-evaluated in order for adjustments to be implemented (OECD, 2012b).

Ecological tax reform was launched in 1999 and revised in 2003. Under the reform, taxation on high electricity consumption was introduced and excise duties on fossil fuels were increased. Resulting revenue was used to reduce social security contributions. It has been estimated that the taxation mechanism led to GHG emissions reduction, increased employment and had a positive effect on technological innovation (Knigge and Gorlach, 2005). On the other hand, it has been argued that the effectiveness of the reform is restricted by a number of issues, such as the high number of tax exemptions and lack of adjustment of tax rates for inflation (OECD, 2012b).

Sector-specific policies have also been implemented, perhaps most notably in the energy sector (See Box A.1). Investment in renewable generation has been encouraged through the feed-in tariff (FIT) scheme, which was introduced in the early 1990s and readjusted in the 2000s. FITs were introduced to provide long-term certainty for investors and as a result, variations of the scheme have been implemented in a number of countries worldwide. FITs guarantee the price for renewable electricity generation at a declining rate over a 20-year period. Priority access to the electricity market for renewable producers was also introduced at the same time.

The interaction between the EU and national climate policies has also been a source of criticism, particularly in relation to the EU Emissions Trading Scheme (ETS). The OECD reports that the cost-effectiveness of the ETS can be weakened by national policy instruments, resulting in a lack of incentives for emissions reduction (OECD, 2012b). In that context, close coordination between national and EU policies is imperative (Frondel *et al.*, 2010).

1.3 The Impacts of Green Growth Policy

The effects of the German climate policies and environmental technology export strategies have started to become evident in a number of indicators.

It was reported that in 2010, the renewable energy sector was responsible for the creation of 370 000 jobs (Janicke, 2012). According to the BMU, a rise of approximately 70% in green technology-related positions is expected between 2012 and 2025, with green employment reaching 2.4 million in 2025 (BMU, 2012). Nevertheless, it is not easy to assess the net impacts of Germany's policies that also take into account the loss of employment in declining industries (OECD, 2012b).

In terms of economic growth, analysis by the BMU forecasts that environmental technologies will constitute 15% of the national GDP by 2025, compared to 11% in 2012 (BMU, 2012).

Germany also seems to be on the right path to achieve its ambitious long-term GHG reduction targets. At the end of 2010, GHG emissions were reported to be 23% below 1990 levels, far surpassing national emissions reductions targets (Schreurs, 2012).

The BMU also projected an encouraging outlook regarding Germany's position in the international green technology market. It was calculated that in 2012, Germany made up 15% of the world market in green technologies. Nonetheless, the threat from emerging markets, such as China, was also acknowledged(BMU, 2012).

Box A-1: The *Energiewende* and the transition towards renewable energy

Germany's support for renewable energy, and a wider *Energiewende* (energy transition), is the focus of much international discussion. Germany's initial interest in non-fossil energy sources can be traced back to the 1970s oil crisis. Energy R&D expenditure was increased to reduce dependence on oil and to strengthen energy security. Between 1974 and 1983, energy R&D spending rose more than ten-fold, targeting renewable energy, nuclear and coal (Laird and Stefes, 2009).Whilst most of this spending was directed to coal and nuclear technologies, renewable energy was also supported – including several wind and solar power demonstration projects (Jacobsson and Lauber, 2006). Political support for renewable energy technologies also gained momentum over the same period. For example, the first renewable energy trade associations were formed (Laird and Stefes, 2009).

Explicit support for renewables was strengthened during the 1980s for two main reasons. The 1986 Chernobyl nuclear accident led to deep concerns about nuclear safety and resulted in significantly reduced support for the industry among the German public. At the same time, there was increasing pressure to discontinue public subsidies for the German coal industry due to associated environmental pollution. The incremental tightening of Germany's environmental targets over the last two decades is also linked to the increasing popularity of the German Green Party. The 'Red-Green Coalition' that entered government in 1998 is considered a significant milestone in Germany's green growth transition (Iwulska, 2012; Schreurs, 2012).

More recently, Germany's 2010 'Energy Concept' policy included an increasingly pivotal role for renewable energy, energy efficiency, energy R&D and the development of new grid infrastructure. The most controversial aspect of these reforms was the reinstated support for nuclear power through lifetime extensions of existing plants of between eight to 14 years. Following the 2011 Fukushima nuclear accident, strong public opposition led to the immediate shut down of eight plants and a plan to phase out the country's remaining nine plants by 2022 (Schreurs, 2012).

Germany's level of ambition has increased further recently. The targeted share of renewable electricity generation has been increased to 35% – 40% by 2020, 50% by 2030, 65% by 2040 and 80% by 2050. A 60% target for primary energy by 2050 has also been established. In terms of energy efficiency, a target for a 20% reduction in primary energy use by 2020 compared to 2008 levels was introduced, increasing to a 50% reduction by 2050. A carbon emissions reduction target of 80% by 2050 compared to a 1990 baseline was also established (Schreurs, 2012).

Support for renewable energy has led to rapid deployment growth. The share of renewable electricity generation grew from 5% of electricity in 1998 to well over 20% today (Janicke, 2012). However, there have been criticisms of the policy, particularly since the nuclear phase-out was implemented. These criticisms include the financial impact of FITs on consumer electricity prices and the risk of technological lock-in (Frondel *et al.*, 2010; OECD, 2012b). They have also focused on the recent increase in coal-fired generation, fuelled by cheap coal, to compensate for the reduction in nuclear power output. This led to increased German carbon emissions in 2012 and 2013. It remains to be seen whether this is a temporary phenomenon.

2. South Korea as a Case Study of Green Growth

South Korea has experienced significant economic development in the past decades. Rapid industrialisation led to a steep increase in carbon emissions and a heavy dependence on fossil fuel imports, while urbanisation put pressure on the natural environment.

South Korea was established in 1948 and was originally an agrarian society. In fact, in 1960 it was considered to be one of the least industrially developed societies worldwide (Kim *et al.*, 2011). However, over the last three decades rapid industrialisation has taken place, leading to a well-developed export-focused economy, a rise in living standards and a significant increase in energy consumption and associated GHG emissions.

Over the period 1980 to 1990, the average GDP annual growth rate was 10%, dropping to 6.1% between 1990 and 2003 and then further declining to 4.8% until 2007. Despite a general upward trend, GDP growth rates have significantly decelerated since the global economic recession, dropping for the first time below 4% (Zelenovskaya, 2012). Even so, it is noteworthy that a relative reduction in growth rates as economies mature is not uncommon. Spence (2012) states that consistent growth rates above 7% are unlikely in developed countries.

South Korea's economic growth is largely based on energy-intensive industries (steel, cement, petrochemicals, automobiles, etc.). Energy demand trends show that in the last two decades the industrial sector has accounted for more than half of the final energy use (Kim *et al.*, 2011). The residential sector was also a main driver behind the rise in energy consumption and emissions due to the rise in living standards linked to economic growth (Jones and Yoo, 2011).

As a result of industrialisation and economic development, a steep increase in energy consumption and GHG emissions has occurred. The trend in GDP growth is reflected in GHG emissions; between 1990 and 2005, Korea's GHG emissions presented the highest rate of increase among OECD countries and almost doubled in total (Jones and Yoo, 2011). Indeed, in 2008, Korea was reported to be the 10^{th} largest primary energy consumer and the tenth largest emitter of CO_2 worldwide (Zelenovskaya, 2010). GHG emission trends are shown in Figure A.1.

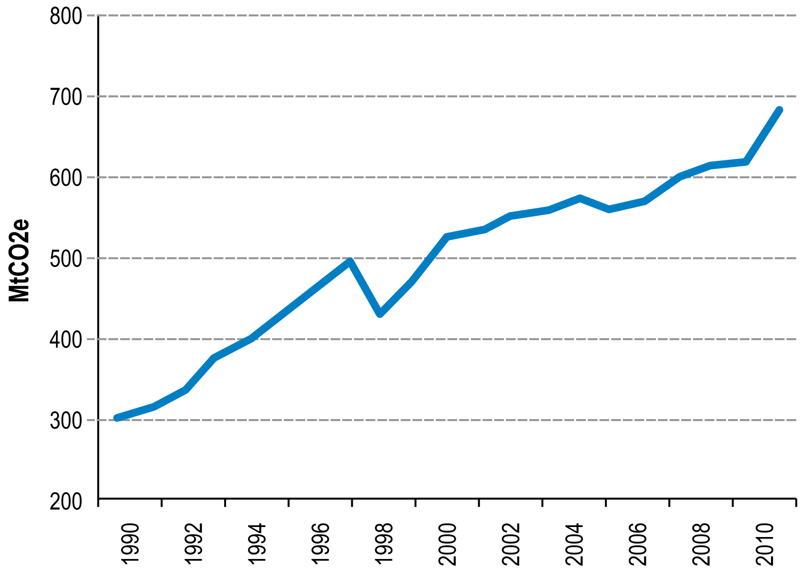

Figure A.1: South Korean GHG emissions, excluding land-use change & forestry. Data from the CAIT 2.0 beta tool, World Resources Institute

While the carbon intensity of South Korea's economy has declined since the mid-1990s, it is still high compared to other OECD countries. According to the IEA, in 2004, South Korea's carbon emissions per unit of GDP were 15% higher than the IEA average and approximately 23% higher than the IEA Pacific average (IEA, 2006). In terms of energy supply, South Korea's supply mix is largely fossil fuel-based, with renewable and nuclear power accounting for under a fifth of the mix (Zelenovskaya, 2012). This has led to a heavy dependence on fossil fuel imports. In 2007, Korea's energy imports were calculated at approximately 97%, rendering the country particularly sensitive to international price fluctuations (Kim *et al.*, 2011).

2.1 South Korea's Green Growth Strategy

To respond to the environmental pressures associated with industrialisation and to revitalise the economy in the wake of the global financial crisis, a turn towards green growth was announced by then President Lee Myung-bak in 2008 (PCGG, nd). The announcement was followed by the launch of a stimulus package labelled as a "Green New Deal" equal to approximately 38.1 billion USD, i.e. approximately 4% of the country's GDP, to be allocated between 2009 and 2012. The main sectors covered in the stimulus package were new and renewable energy technologies, energy efficiency in the built environment, green infrastructure (e.g. railways), green transport (e.g. low-carbon vehicles) and water and waste management, signifying a shift towards a low-carbon economy (Zelenovskaya, 2012). In total, 36 projects were assigned in the Green New Deal with a focus on water and waste management and railroad transport, which respectively accounted for 33% and 28% of total funds. A sectoral breakdown of budget allocation can be found in Table A.1.

Table A.1: Green New Deal sectoral breakdown

Sector	Expenditure (trillion won)	Expenditure (%)
Water & waste management	13	33%
Railroad transport	11	28%
Energy efficient buildings	10	25%
Low-carbon vehicles	3	8%
Renewable energy	3	8%
Total	**40**	

Source: Jones and Yoo (2011)

Due to the level of dependence on fossil fuel imports and the carbon-intensity of the economy, it has been argued that the promotion of green growth is a suitable strategy for South Korea (Mathews, 2012). Kang *et al.* (2012) also report that heavy dependency on resources and fossil fuel imports in combination with reduced economic growth rates were behind the country's economic model shift. A significant aspect of that was the change in the international export market due to rising competition by emerging economies such as China and India (Kang *et al.*, 2012). Moreover, green growth was presented by the South Korean government as a way to regenerate the economy and create employment in the green technology and renewable energy sectors (PCGG, 2009).

Signalling the government's commitment to a low-carbon economy was the announcement of an ambitious target of 30% reduction in carbon emissions by 2020 compared to 'business as usual'. This figure translates into a 4% reduction from 2005 levels (Jones and Yoo, 2011). "Negotiated agreements with specific companies the industry, power generation and agricultural sectors were implemented by the government under the Target Management System. There is a plan to replace the Target Management System with an emissions trading scheme, though implementation has been delayed."

Strong central leadership is considered to be a critical aspect to the success of Korea's green growth strategy. A top-down approach was followed, with the Presidential Commission on Green Growth (PCGG) being established as an inter-ministerial body in 2009 to coordinate and monitor the implementation of the green growth strategy. The PCGG involves delegates from all the main governmental departments that are associated with the transition, i.e. the Ministry of Environment, the Ministry of Knowledge Economy, the Ministry of Land, Transport and Maritime Affairs and the Ministry of Food, Agriculture, Forestry and Fisheries (Kang and Kim, 2012). The National Strategy for Green Growth was issued by the PCGG in 2009, with a time horizon that extends to 2050.

The National Strategy defines three broad objectives and ten policy directions, each designed to support the application of one of the objectives (PCGG, 2009). While the environmental component is strong, it is essentially an economic strategy, designed to promote technological innovation, support the commercialisation of key green technologies and lead to economic growth and employment generation.

Implementation will be via a return to 5-Year Plans. These plans were first introduced in South Korea in 1962 and were considered pivotal during the country's industrialisation period. They were later deemed ineffective and were therefore abandoned in the mid-1990s (PCGG, 2009; Mathews, 2012). The first 5-Year Plan for Green Growth covered the period from 2009 to 2013. According to the 5-Year Plan, public annual investment in green growth was projected to be approximately 2% of the GDP (Zelenovskaya, 2012).

Total investment over the 5-year period was planned to be 107 trillion KRW (~ $86 billion). More than half of that was assigned to the construction sector, related to policy directions (PCGG, 2009). In total, 600 projects were included, absorbing the earlier Green New Deal. Emphasis was placed on the upgrade and expansion of the national rail transport system and water and waste management. Indicatively, the Four Rivers Restoration Project, one of the key water management projects, accounted for approximately 14% of the 5-Year Plan budget. In contrast R&D was allocated only 12% of the total expenditure (Jones and Yoo, 2011).

Criticism has been expressed on the focus of the strategy on the construction sector and in particular the Four Rivers Restoration Project, a large-scale water conservation project. Environmental groups and members of the academic community under the Professors' Organisation for Movement against Grand Korean Canal have expressed concern that the intended restoration project will in fact have a harmful effect on the local ecosystem and may lead to habitat loss. The effectiveness of the engineering approach followed in the project and the reported cost assumptions have also been challenged (Normile, 2010).

2.2 The Development and Deployment of Green Technologies

The development of green technologies is a major theme in South Korea's green growth strategy. Commercialisation is an important aspect of that goal, as Korea aims to increase its share of the international green technology market to 10% by 2020, compared to 2% in 2009 (PCGG, 2009).

Following a formal consultation process and based on potential contribution to economic growth, environmental impact and strategic importance, a list of 27 technologies, which are expected to be prioritised in the country's R&D strategy, have been included in South Korea's green growth plan (Table A.2). While a number of the 27 core technologies are directly related to climate change mitigation, energy and the environment, others are broader in scope and can be considered 'green' in the context of a general shift towards a more sustainable growth paradigm (Kang and Kim, 2012).

Table A.2: Core green technologies (UNEP, 2010a)

Sector	Core Green Technologies	Timing
Climate Change	1. Monitoring and modelling for climate change	Long term
	2. Climate change assessment and adaptation	Long term
Energy Source Technology	3. Silicon-based solar cells	Short term
	4. Non-silicon based solar cells	Long term
	5. Bio-energy	Long term
	6. Light water reactors	Short term
	7. Next-generation fast reactors	Long term
	8. Nuclear fusion energy	Long term
	9. Hydrogen energy R&D	Long term
	10. High-efficiency fuel cells	Long term
Technologies to Improve Efficiency	11. Plant growth-promoting technology	Long term
	12. Integrated gasification combined cycle	Long term
	13. Green cars	Medium term
	14. Intelligent infrastructure for transport and logistics	Long term
	15. Green city and urban renaissance	Long term
	16. Green buildings	Long term
	17. Green process technology	Medium term
	18. High-efficiency light-emitting diodes/green IT	Short term
	19. IT-combined electric machines	Long term
	20. Secondary batteries	Medium term
End-of-pipe Technology	21. CO_2 capture, storage and processing	Long term
	22. Non-CO_2 processing	Medium term
	23. Assessment of water quality and management	Medium term
	24. Alternative water resources	Medium term
	25. Waste recycling	Medium term
	26. R&D in monitoring and processing for hazardous substances	Long term
R&D in Virtual Reality	27. Virtual reality	Medium term

The attraction of private R&D investment and the greening of existing industries are considered key parameters for the success of the Green Growth Strategy. While the government's fiscal commitment initially focused on construction and green infrastructure projects, with R&D making up 12% of total expenditure, it was expected that financial support for R&D would increase as the economy recovered (PCGG, 2009). This has succeeded to an extent. While increased investment in green technologies was observed following the launch of the green growth strategy, it did not reach the anticipated level (Zelenovskaya, 2012).

Tax incentives and other policies were implemented to attract private investment in green technologies and industries. A green certification scheme was introduced in 2010, coordinated by the Korea Institute for Advancement of Technology[11]. Funds that focus 60% of their investment in certified firms and projects were granted tax exemptions. Furthermore, there was an increase in government lending for green projects of 150% between 2009 and 2013, as well as the launch of a green equity fund (Jones and Yoo, 2011).

To support carbon emissions reduction, the South Korean government is also implementing a carbon ETS. The introduction of an ETS is facilitated by the Framework Act on Low-carbon Green Growth, which dictates carbon reporting by all the major energy-intensive industries (UNEP, 2010a). The detailed legislative framework for the scheme was approved by the Korean National Assembly in 2012, with the scheme expected to take effect in 2015 (Mathews, 2012). It is notable that South Korea already has the experience of implementing a cap-and-trade scheme covering NOx, SOx and total suspended particles, established in 2008, which would facilitate the introduction of the ETS (Jones and Yoo, 2011).

The National Strategy explicitly targets the increase of renewable energy in South Korea's energy mix. A renewable portfolio standard was introduced in 2012 to help meet this target, and to replace the earlier FIT scheme that had been in place since 2002. The renewable portfolio standard specifies a mandatory percentage of renewable energy generation for energy service companies. It is anticipated that the required share will reach 10% by 2022 (Kang and Kim, 2012).

[11]The Green Certification system certifies technologies, projects and firms that are in alignment with the Korean Green Growth vision based on a range of criteria. Firms are considered 'green' when more than 30% of their sales are associated with certified technologies (Jones and Yoo, 2011).

Appendix 4: R&D Priorities for PV Systems

- Advanced PV cell and module characterisation and performance verification: PV technologies have been consistently developed over the past few decades, with advances in the standard crystalline and thin film technologies. PV module qualification techniques are well established with several accredited facilities worldwide. With the expected large-scale deployment of PV in South Africa there is a need for the development of a local facility that is able to perform advanced PV cell and module characterisation.
- Building integrated photovoltaics: The successful implementation and operation of energy efficient building integrated PV housing, hinges on the appropriate design of the passive solar features, the PV system and integration thereof, and the domestic SWH.
- Development of concentrator photovoltaic (CPV) technology for deployment in South Africa, and elsewhere: Concentrator photovoltaic (CPV) systems have the potential to reduce the cost of PV electricity, thereby attaining grid-parity well before conventional flat plate PV. The solar resource in South Africa, with extensive areas with high irradiance makes the deployment of CPV attractive, particularly if CPV modules can be manufactured locally.
- Basic investigation of new PV technologies: There are several materials systems that are currently being investigated with the aim of developing new, high-efficiency devices (third-generation devices). These devices make use of the properties of the different materials or low-dimensional structures to enhance photon absorption and/or photo-generated current, thus resulting in higher efficiencies.
- Electrical storage: Another technical barrier is that of electrical storage, which is central to addressing the peak demand profile of the country. R&D initiatives are attempting to address the life cycle cost aspects of a variety of battery options (NiMh, Lithium, NaS/NaNiCl, Lead-acid, Zinc-bromine, V-redox-flow), and the next five years should be used to identify the potential role of the South African R&D community in this space; at both the basic and applied levels.

Appendix 5: Models of Technology Adoption

1. Innovation Diffusion Theory

According to the Innovation Diffusion Theory, a person moves from first knowing about a particular innovation (knowledge stage), to forming an attitude about that innovation (persuasion stage), to making a decision whether or not to use a particular innovation (decision stage), to using an innovation (implementation stage), to finally deciding whether to continue using an innovation (confirmation stage) (Rogers, 2003).

The primary engagement of a consumer with a technology in the decision process is at the persuasion stage. There are five innovation attributes/predictors at the persuasion stage: relative advantage, compatibility, complexity, trialability and observability. Relative advantage describes how useful a potential user feels the innovation is in relation to other available innovations. Compatibility considers how well the innovation matches the perceived needs of the user. Complexity refers to how difficult an innovation is to use (or to learn to use). Observability is the extent to which the innovation is visible amongst peers and social groups. Finally, trialability refers to the effort or risk involved in experimenting with prototypes or early versions of an innovation and the ability to recover from errors.

2. Technology Acceptance Models

One of the most widespread and empirically tested models of technology acceptance is the Technology Acceptance Model (TAM) (Davis, 1989). The TAM is loosely based on Ajzen and Fishbein's (1980) psychological theory of reasoned action, although it replaces many of the attitudinal components in this theory with only two technology-related attitudes, perceived usefulness of the technology and perceived ease of use of the technology. Davis (1989) argued that high positive ratings of these two attitudes would lead first to intentions to use a particular technology and then, if the intention levels were high, directly to the actual use (behaviour) of that technology. The TAM has been tested successfully on a wide variety of technologies including general information systems, computer applications, email, telemedicine technology, the World Wide Web, and mobile phone applications, amongst others. In the original conceptualisation of the TAM, Davis (1989) used a 'catch all' factor called external variables to incorporate unexplained influences on the relationships. Typical external variables used in previous studies included past experience with the technology, gender, age, and previous education (e.g. Morris and Venkatesh, 2000; Venkatesh and Morris, 2000).

Despite the TAM being one of the most widely used and replicated instruments for predicting technology use, the model has been critiqued as being too simplistic (e.g. Gefen and Straub, 1997; Legris *et al.*, 2003). Venkatesh and Davis (2000) extended the original TAM to TAM2 by elaborating on the external variables in order to include social influences (i.e. social norms, voluntariness, and image), perceived instrumental factors (i.e. perceived relevance and perceived output quality), and the user's past experience.

One primary critique of both the TAMs and Innovation Diffusion Theory is that they assume that the adoption of innovations/technology is based entirely on the features or qualities of the technology; what Green (2001) refers to as "technological determinism". Green (2001) proposed that the social circumstances (i.e. the economic and political environment, and the existing social and physical infrastructure) also have a significant impact on determining technology development and use.

Musa's (2006) extension of the TAM2 addressed this problem by introducing the concepts of values, accessibility, and exposure to target technology. Musa (2006) built on Mathieson *et al.*'s (2001) perceived user resources model, which is based on the extent to which an individual believes that they have the personal and organisational resources to use the technology. Mathieson *et al.* (2001) conceptualised this in terms of four elements: user attributes such as expertise, training, educational level, and time available to learn the technology; support from others, such as technical support and help-desk support; system attributes such as accessibility and cost; and control-related beliefs including perceived behavioural control. Musa (2006) added three further constructs (Figure A.2): perceived positive-impact factors, perceived negative-impact factors, and the individual's perception of the socio-economic environment.

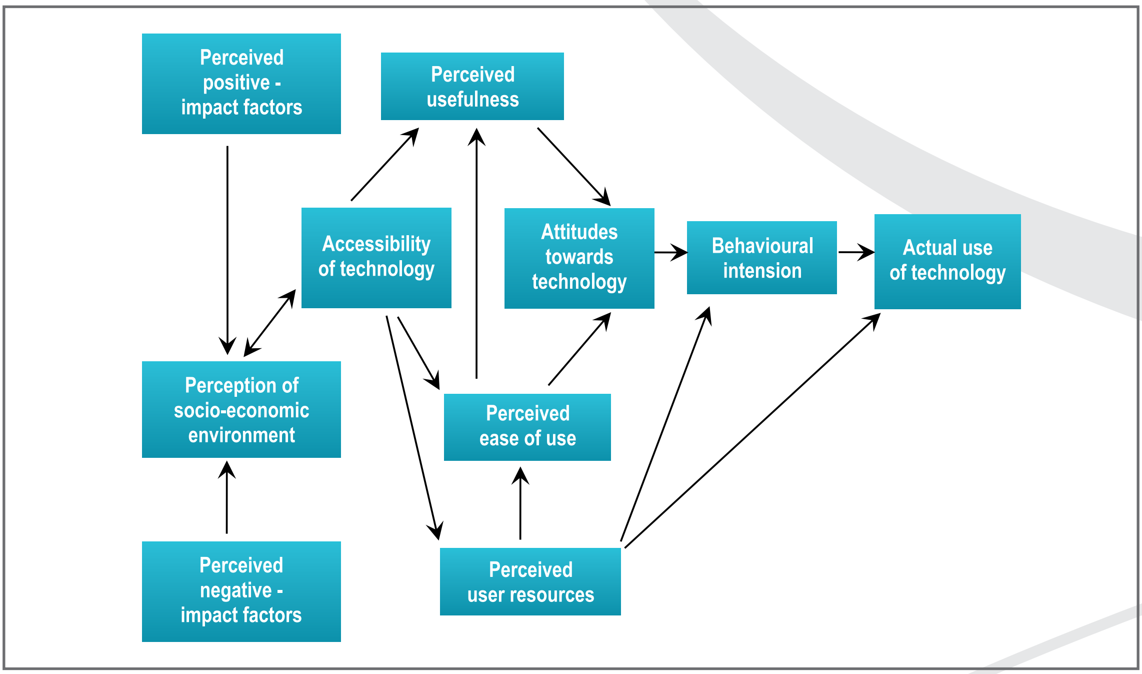

Figure A.2: Musa's extension of the Technology Acceptance Model (Musa, 2006; p. 217)

The perception of the socio-economic environment is influenced by both positive and negative factors. Positive factors include economic activity, good health systems, good governance, transport infrastructure, employment, and good education systems. Negative factors include unemployment, poverty, corruption, bribery, and minimal access to basic resources (i.e. water, food, electricity, education, and housing). According to Musa (2006), the adoption of technology is facilitated by positive factors and inhibited by negative factors. This suggestion places a significant burden on the state and the political environment to create a supportive environment for technology adoption. Musa's model suggests a two-way interaction between the socio-economic environment and access to technology, implying that the lack of access to technology would drive the negative-impact factors, while access to technology would result in the opposite outcome.

3. Unified Theory of Acceptance and Use of Technology (UTAUT)

Venkatesh *et al.* (2003) combined various models to produce the Unified Theory of Acceptance and Use of Technology (UTAUT). The UTAUT comprises four determinants (i.e. performance expectancy, effort expectancy, social influence, and facilitating conditions) that predict intentional behaviour, which in turn predicts actual behaviour. In addition, the model hypothesises that there are four moderating factors (i.e. gender, age, experience, and voluntariness) that influence the strength of the relationships between the determinants and behavioural intention.

4. Affective and Persuasive Design

Another branch of technology adoption has also considered the emotional or aesthetic appeal of the innovation/technology. This is an area of study broadly referred to as "affective design". These theories emphasise the relationships between the end user and the qualities of the technology. In order to understand how "affect" operates in consumer decision-making, Khalid (2006) developed a model, in which the first step is the matching of consumers' perceived needs with the characteristics of the product. Perceived needs might include aspects such as cost-reduction, learnability, usability, entertainment, attractiveness, and status improvement. The second step is the trial adoption of the product ("in-shop") where the product is evaluated against their needs. The final step is the adoption (or rejection) of the product. Khalid's model looks expressly at understanding something about what the user needs and then designing the technology to match that need. Affective design suggests that technologies that match user needs will garner more positive attitudes and therefore will be more likely to be adopted.

In related work, persuasive design considers technologies that are specifically designed to get users to make constructive changes to their behaviours, motivations, and attitudes (Fogg, 2003). What is different about persuasive design is that the technological design aims to influence behaviour change in the user irrespective of the user's perceived needs (i.e. the technology is designed in a way that persuades us to behave in a particular way). For this reason, Fogg (2003) warns that persuasive design should be tempered by ethical responsibilities to ensure that the influence is not abused. In later work, Fogg (2009) proposed the Fogg Behavioural Model that suggests that persuaded behaviour is achieved through matching motivation, abilities and triggers. From a motivation perspective, Fogg (2009) argued that there were three primary motivators: sensation (pleasure/pain), anticipation (hope/fear), and social cohesion (acceptance/rejection). Technology is more persuasive in situations where one (or a combination) of these motivators is high. Ability refers to the capacity to carry out the intended target behaviour. Fogg (2003) argued that simplicity (of interaction with the technology) is central to persuasion and identified six elements: time, money, physical effort, mental effort, social deviance, and non-routine behaviour. In many ways these qualities are very similar to the UTAUT's effort expectancy and social influence. Finally, Fogg (2003) identified three types of triggers: facilitators (makes a behaviour easier), sparks (motivates a behaviour), and signals (indicates or reminds a person of the behaviour).

5. Other Personal and Psychological Influences

In addition to the major theoretical models discussed above, various other researchers have proposed important components to consider as determinants of technology adoption. For example, Porter and Donthu (2006) found that usage behaviours were related to the purposes for which people used the technology. In other words, if people have an incentive to use the technology they were likely to overlook the perceived barriers. Venkatesh (1999) extended the UTAUT by treating intrinsic motivation as an external variable preceding perceived ease of use and perceived usefulness. Venkatesh (1999) found that user acceptance of technology was higher amongst the group that was intrinsically motivated to use the technology. Working within a Theory of Planned Behaviour framework, Venkatesh and Brown (2001) found that technology adoption was higher for those driven by social, hedonic, and utilitarian outcomes.

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